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COMPARATIVE TEST OF THE OH-6A ENGINE INLET FILTER AND PARTICLE --ETC(U)
APR 68   C L RAYMOND, R J FOLLOWILL

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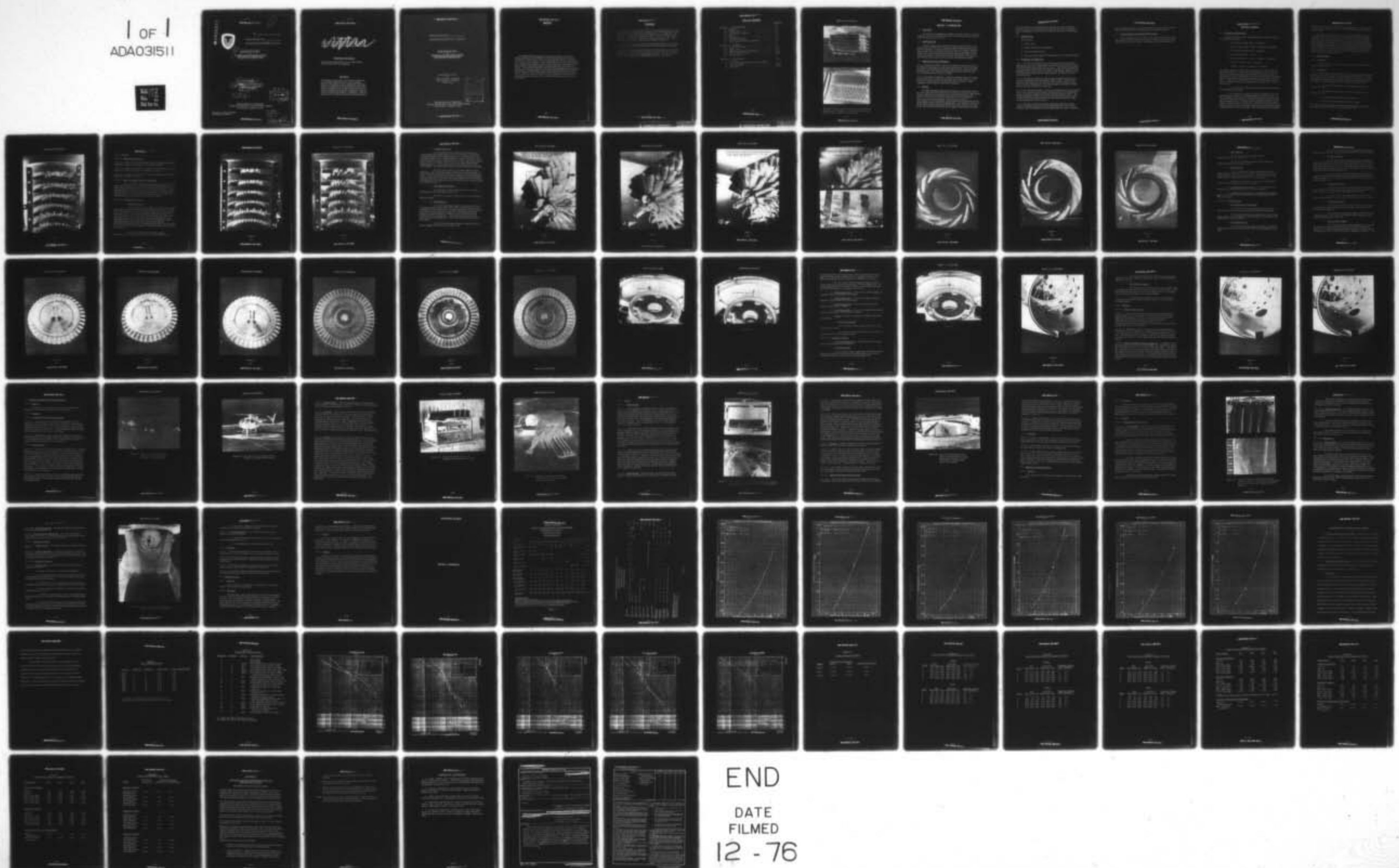

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RDT&E PROJECT NO.

USATECOM PROJECT NO. 4-6-0251-05

COMPARATIVE TEST of THE OH-6A ENGINE INLET FILTER AND PARTICLE SEPARATOR.

Final Report of Test
by
Major Charles L. Raymond
Mr. Richard J. Followill

1 April 1968

87p.

DEPARTMENT OF THE ARMY
UNITED STATES ARMY AVIATION TEST BOARD
Fort Rucker, Alabama 36360

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ABSTRACT

The USAAVNTBD comparatively tested the Barrier Filter and Particle Separator on the OH-6A at Yuma Proving Ground, Arizona, 29 October - 24 November 1966, accumulating 15.5 hours of operation on three calibrated engines. The engines protected by the Particle Separator suffered less visible erosion, less performance degradation and less moisture impingement than the engine protected by the Barrier Filter. The Particle Separator required less maintenance and servicing, was easier to maintain and service, and had fewer malfunctions (none) than the Barrier Filter which experienced malfunctions in three areas. The test directive specified that the report contain no conclusions and recommendations because of the "possible controversial nature of the test results."

FOREWORD

The Commanding General, US Army Test and Evaluation Command (USATECOM), directed the comparative test of the OH-6A Engine Inlet Filter and Particle Separator by 1st Indorsement, AMSTE-BG, Headquarters, USATECOM, 9 September 1966, to letter, AMCPM-LHT, Headquarters, US Army Materiel Command, 26 August 1966, subject: "Test of OH-6A Engine Inlet Filter and Particle Separator."

The US Army Aviation Test Board (USAAVNTBD) was responsible for planning and conducting the test and for reporting the test results.

Personnel other than the authors who were closely associated with this project are Paul W. Bass, planner, and LTC Cornelius J. Radu, Chief, Instrumentation and Methodology Division. Test data are filed at the USAAVNTBD under USATECOM Project No. 4-6-0251-05.

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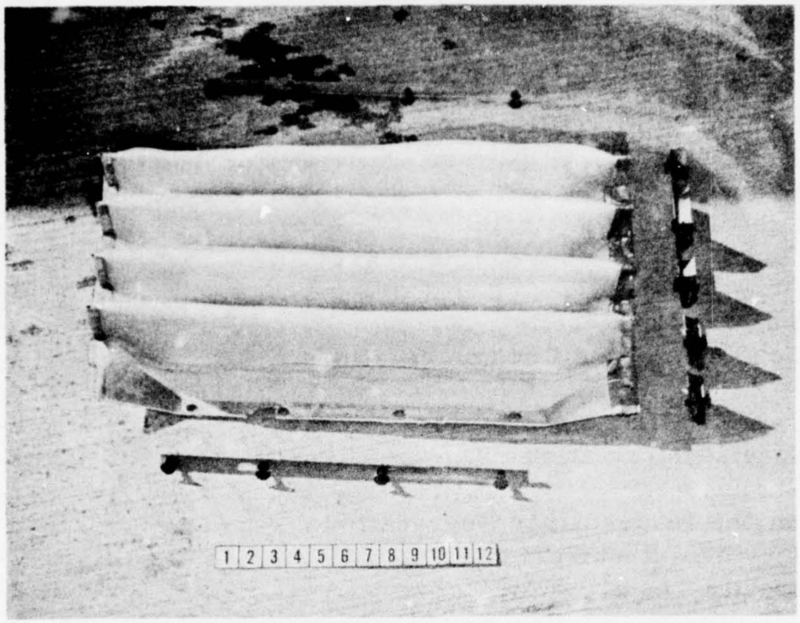
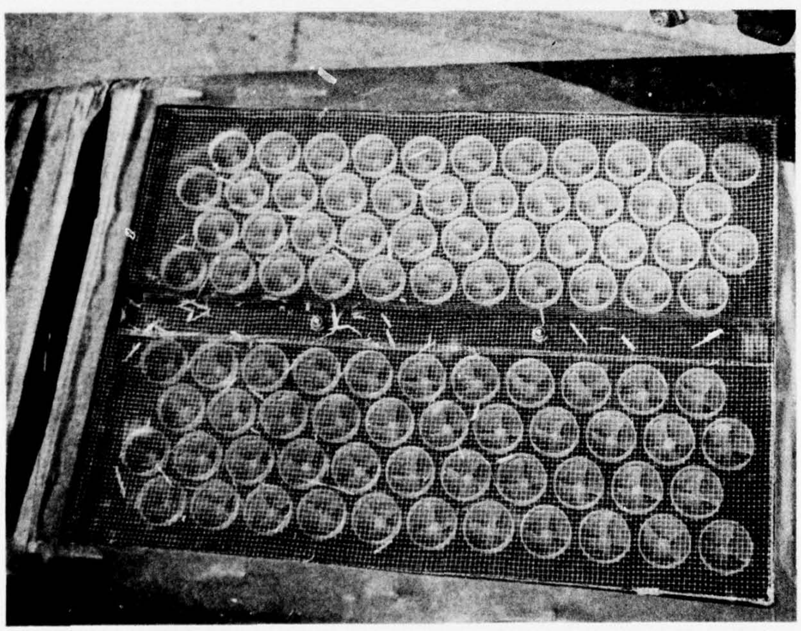




The Barrier Filter with snap fastener devices (above) and the Particle Separator showing protective screen and 88 inertial separator tubes (below).

SECTION 1 - INTRODUCTION

1.1. PURPOSE.

To determine comparatively whether a barrier filter or a particle separator is the more suitable test item for removing foreign material from the OH-6A engine inlet air.

1.2. BACKGROUND.

Various turbine-powered aircraft in the service inventory have experienced a problem with compressor blade erosion owing to sand and dust ingestion. Results of desert testing of the YOH-6A indicated that an engine air-inlet protection device would be needed to prolong engine life. Under the product-improvement program (PIP) with the engine manufacturer and a direct contract with another manufacturer, two sand and dust protective devices were fabricated for testing.

1.3. DESCRIPTION OF MATERIEL.

1.3.1. The Barrier Filter, which was installed within the fuselage of the YOH-6A Helicopter aft of the mast and above the T63-A-5A engine bellmouth, incorporated a removable filter element constructed in an accordion-like, four-pleated configuration having an effective filter area of approximately 740 square inches.

1.3.2. The Particle Separator, which was installed within the engine air-inlet fairing aft of the mast and above the engine bellmouth, consisted of a metal framework mounting 88 small, tubular, inertial separators constructed of a nylon-like material.

1.4. SCOPE.

The USAAVNTBD conducted this Category II comparative test of the two engine protective devices in the vicinity of Yuma Proving Ground, Arizona, during the period 29 October 1966 to 24 November 1966. A total of 15 hours and 30 minutes of operation was accumulated on three calibrated engines during which operation in various environments was accomplished. Report has been held pending receipt of the engine analysis from the manufacturer. For purposes of this test, the drop in pressure (Δp) across the Barrier Filter element was measured, and was read by the pilot from a gauge on the instrument panel.

Measuring devices and indicators provided the pilot with readings of pressure drop across the protective system of the Particle Separator and of scavenging air pressure which indicated operation of the exhaust fan.

1.5. OBJECTIVES.

To determine:

a. Engine wear.

b. Engine performance degradation.

c. Servicing requirements.

d. Foreign object migration characteristics of the Barrier Filter.

1.6. SUMMARY OF RESULTS.

1.6.1. The T63-A-5A engine (S/N 400191) protected by the Particle Separator, experienced significantly less visible erosion than the engine (S/N 400190) protected by the Barrier Filter. The Particle-Separator-protected engine experienced less change in compressor blade and vane fundamental frequencies and in clearance at the balance piston air seal, indicating less erosion than that experienced by the Barrier-Filter-protected engine.

1.6.2. The Particle Separator engine suffered significantly less performance degradation than the Barrier Filter engine. The Particle Separator was superior to the Barrier Filter in protecting the engine from moisture impingement, but neither system was completely satisfactory for hover operation in loose hay.

1.6.3. The Particle Separator required less maintenance and servicing, was easier to maintain and service, and possessed more desirable and fewer undesirable maintenance features than the Barrier Filter. The Particle Separator required no special tools and experienced no malfunctions, while the Barrier Filter required special tools and experienced malfunctions in three areas.

1.6.4. Results of tests to determine migration properties of sand particles through the Barrier Filter during flight were inconclusive because of the impossibility of removing the Barrier Filter, weighing,

and reinstalling without relocating the trapped particles in the element which in turn affected the corresponding Δp reading at a hover.

1.7. CONCLUSIONS AND RECOMMENDATIONS.

The test directive stated, "Due to the comparative nature of this test and the possible controversial nature of the test results, the test reports will not include specific conclusions and recommendations."

SECTION 2 - DETAILS

2.1. SPECIAL INFORMATION.

The test helicopters were operated during 12 flights in various environments as follows:

a. Ground idle in dusty area - 12 minutes.

b. Hover in dusty area - 1 hour, 34 minutes, 40 seconds.

c. Ground idle in sandy area - 12 minutes.

d. Hover in sandy area - 1 hour.

e. Hover in hay area - 1 hour, 14 minutes, 13 seconds.

f. Hover in simulated rain - 40 minutes.

TOTAL - 4 hours, 52 minutes, 53 seconds

The flights ranged in duration from 25 minutes to 1 hour and 20 minutes' total flight time. Each flight was conducted in such a manner that the method and duration of the exposure to sand, dust, hay, or moisture were nearly identical for each of the two YOH-6A Helicopters. Close attention was given to detecting signs of engine wear or loss of power. Criteria were established prior to test by which a determination of significant performance deterioration could be made. These criteria were:

a. The inability of either engine to perform an acceleration check without engine surge.

b. The inability of either helicopter to maintain a five-foot hovering height without (1) exceeding normal rated power limits, or (2) exceeding the maximum limit of the differential in pressure (Δ p) across each protective system, that value being assessed by the LOH Project Manager to be 5.6 inches of water indicated on the pressure gauge in each helicopter (reference 2). Occurrence of either of these conditions would be cause to suspend tests until corrective maintenance (if appropriate) could be performed. The test duration was limited by

directive to a maximum of 20 hours in sand and dust, 2 hours in grass or hay, and 2 hours in moisture, dependent upon the degree of engine deterioration.

Following the comparative test, the calibrated engine in each helicopter was removed. The helicopter with the Particle Separator and with a new, calibrated engine was subjected to 10 hours of additional hovering, equally divided between sand and dust environments to investigate further engine wear (paragraph 2.2) and engine performance degradation (paragraph 2.3). These three engines were returned to the manufacturer for detailed analytical inspection. The helicopter with the Barrier Filter and with a different engine installed was given a special test to evaluate further sand particle migration characteristics of that system (paragraph 2.5).

2.2. <u>ENGINE WEAR</u>.

2.2.1. <u>Objective</u>.

To determine the degree of erosion or wear experienced by the engine during the test.

2.2.2. <u>Technique</u>.

2.2.2.1. Three T63-A-5A engines were calibrated by the manufacturer prior to the start of the test. Specific parts of the compressor and turbine sections were measured. At the end of the test, these same parts were measured again to determine the erosion or wear experienced by the engine. The following parts were measured for comparison:

a. Fundamental frequencies of 10 blades per stage of the compressor rotor.

b. Fundamental frequencies of 10 vanes per stage of the compressor case.

c. Average radius of the balance piston seal.

d. Turbine nozzle flow areas of all four stages.

2.2.2.2. A detailed analytical inspection was performed on all three test engines by the manufacturer at the end of the test.

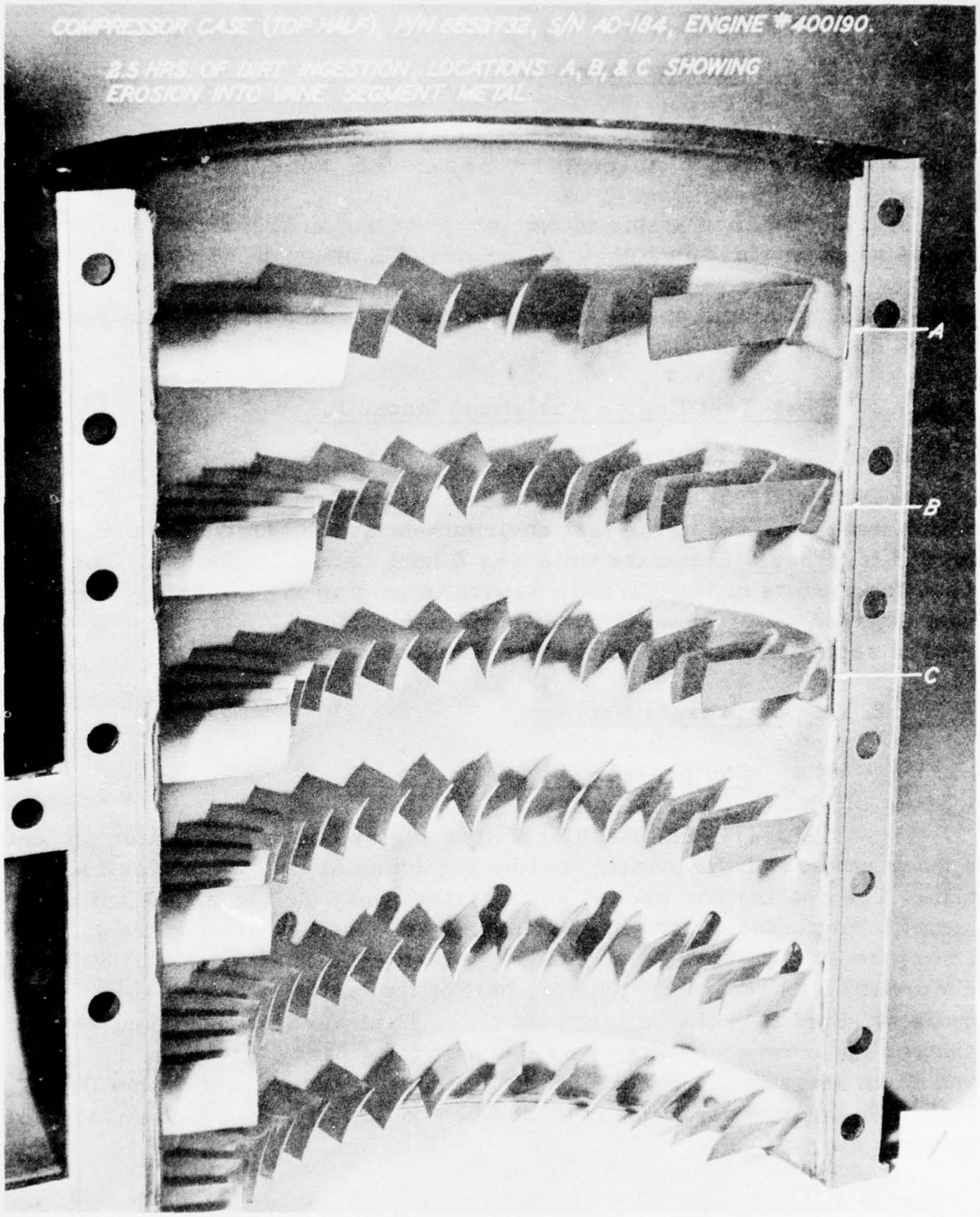

COMPRESSOR CASE (TOP HALF), P/N 6858732, S/N AO-184, ENGINE #400190.
2.5 HRS. OF DIRT INGESTION, LOCATIONS A, B, & C SHOWING
EROSION INTO VANE SEGMENT METAL.
A
B
C

Figure 1

2.2.3. Results.

2.2.3.1. Engine Measurements.

2.2.3.1.1. Blade and vane fundamental frequency measurements are contained in figures 17 through 19, appendix I, section 3.

2.2.3.1.2. Balance piston nickel-graphite air-seal radius measurements are contained in figure 16, appendix I, section 3.

2.2.3.1.3. Turbine nozzle-flow area measurements are contained in figure 23, appendix I, section 3.

2.2.3.2. Post-Test Engine Analytical Inspection.

The results of the analytical inspection of the Barrier Filter engine (S/N 400190) and the Particle Separator engine (S/N 400191) which were exposed to the test environment at the same time are presented together. Exposure time was 2 hours and 27 minutes. The inspection results of the Particle Separator engine (S/N 400192) which was exposed to the sand and dust environment for 10 hours are presented separately except where the results are similar.

2.2.3.2.1. Compressor Section.

a. Compressor Case.

(1) The Barrier Filter engine compressor case showed a wear pattern of the plastic coating beginning at the five o'clock position. The coating had eroded sufficiently to expose the vane segment metal band surfaces at the first through the third stages (figure 1). The third stage was most affected with evidence of slight stator vane undercutting at the root. The top half of the compressor case was more affected than the bottom half. The Particle Separator engine showed the plastic coating was rubbed at the first, fourth, and sixth stage bands (figure 2). Maximum depth of the rub was 0.008 inch. There was no visual evidence of erosion in either half of the compressor case.

(2) The 10-hour Particle Separator engine compressor case showed no visual evidence of erosion (figure 3).

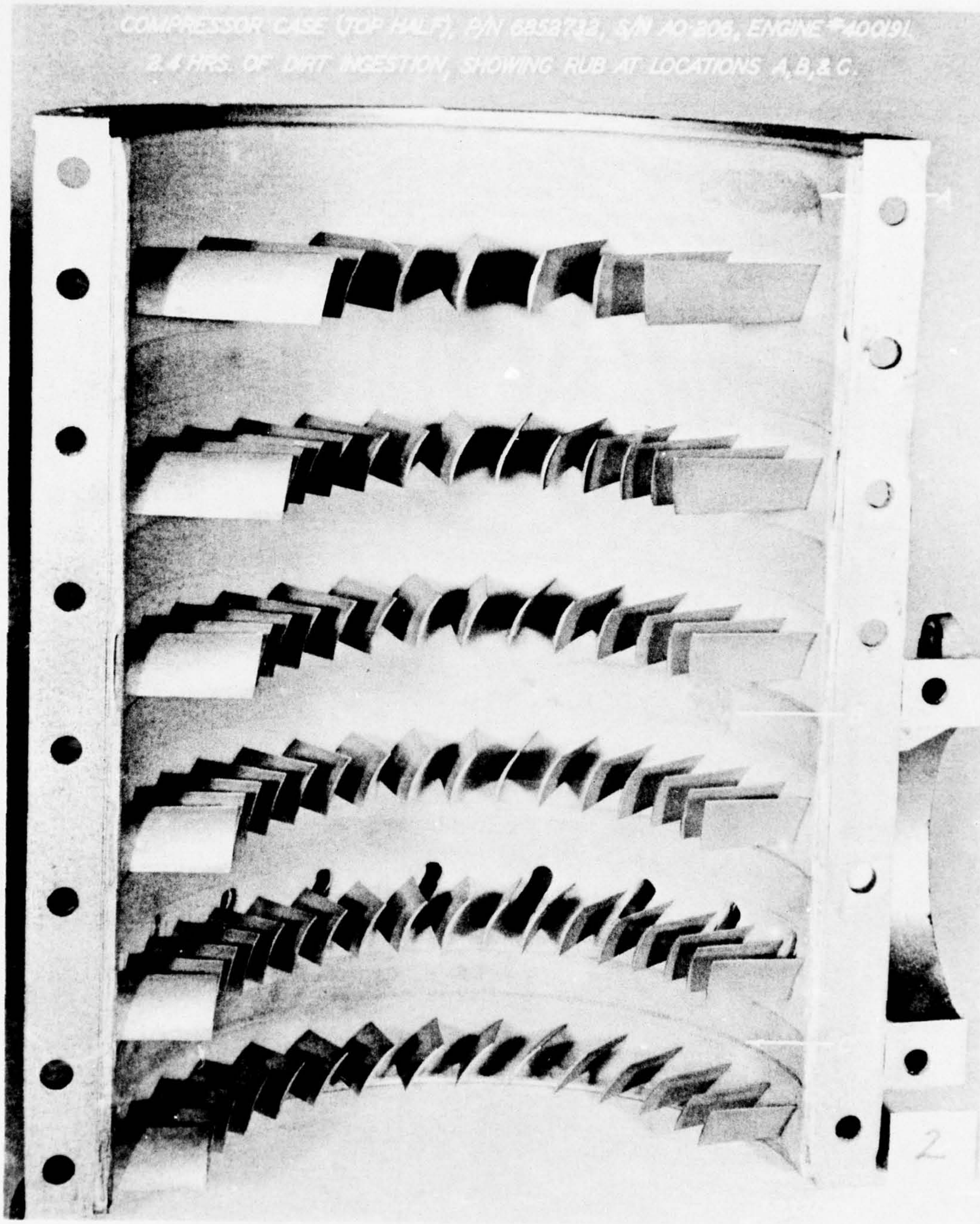

COMPRESSOR CASE (TOP HALF), P/N 6852732, S/N AO-208, ENGINE #400191
2.4 HRS. OF DIRT INGESTION, SHOWING RUB AT LOCATIONS A,B,&C.
2

Figure 2

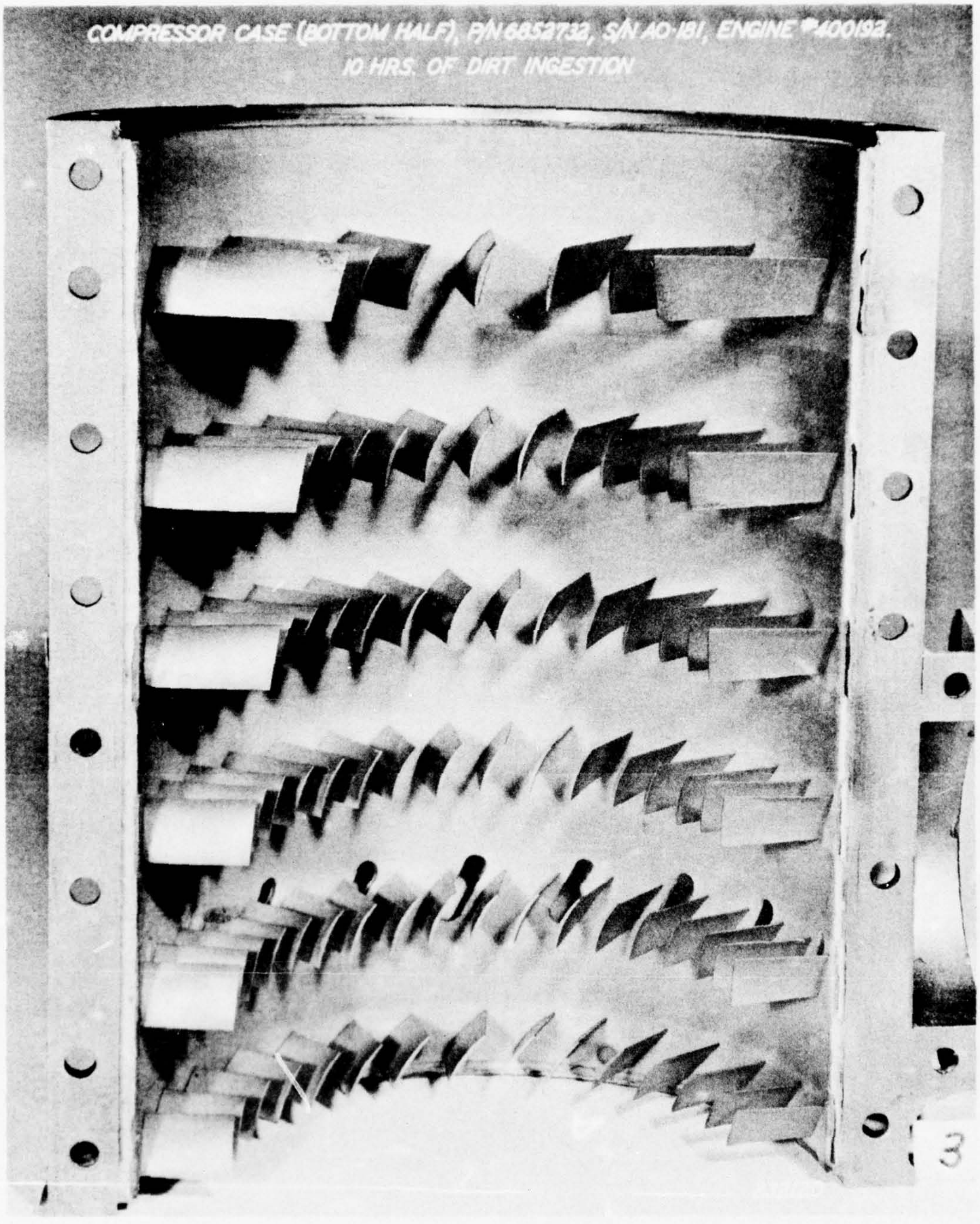

COMPRESSOR CASE (BOTTOM HALF), P/N 6852732, S/N AO-181, ENGINE #400192.
10 HRS. OF DIRT INGESTION
3

Figure 3

b. Compressor Rotor.

(1) The Barrier Filter engine showed first- and second-stage blade leading edge roll-over in the outer one-third (tip area) and slight blade tip rounding (figure 4). The inlet edges of the centrifugal impeller were slightly rounded, evidence of erosion. The Particle Separator engine showed first- and second-stage blade leading-edge roll-over in the outer one-third (tip area) and slight blade tip rounding (figure 5). This erosion was less than that in the Barrier Filter engine. The centrifugal impeller showed no evidence of erosion.

(2) The 10-hour Particle Separator engine showed slight first- and second-stage blade leading edge roll-over (figure 6). This erosion was slightly less than that on the other Particle Separator engine. There was foreign object damage (FOD), cause undetermined, to the trailing edge of one blade of the second stage (0.0625-inch diameter dent) and on the leading edge of one blade of the third stage (0.0625-inch wide tear) (figure 7).

c. Fifth-Stage Bleed Valve.

(1) The Barrier Filter engine showed a slight dirt accumulation on the fifth-stage bleed valve.

(2) There was no dirt accumulation on either Particle Separator engine.

d. Front Diffuser.

(1) The Barrier Filter engine showed a rub area, one inch long and one-half inch wide at the seven o'clock position, on the abradable aluminum-plated face. Dirt had impacted on the face and had accumulated on the guide vanes (figure 8). The Particle Separator engine also showed evidence of impeller rub of 200 degrees on the abradable aluminum-plated face. The deepest rub occurred at the eleven o'clock position (figure 9). There was no dirt build-up on the guide vanes.

(2) The 10-hour Particle Separator engine showed no visible evidence of erosion or wear (figure 10).


COMPRESSOR ROTOR, P/N 6854140, S/N BL243, ENGINE #400190.
2.5 HRS. OF DIRT INGESTION, SHOWING EROSION ON THE
1ST. & 2ND. STAGE BLADE LEADING EDGES.
FOLDS
232105

Figure 4


COMPRESSOR ROTOR, P/N 6854140, S/N BL247, ENGINE #400191.
24 HRS. OF DIRT INGESTION, SHOWING 1ST. STAGE
BLADE LEADING EDGE EROSION.
2
232106

Figure 5

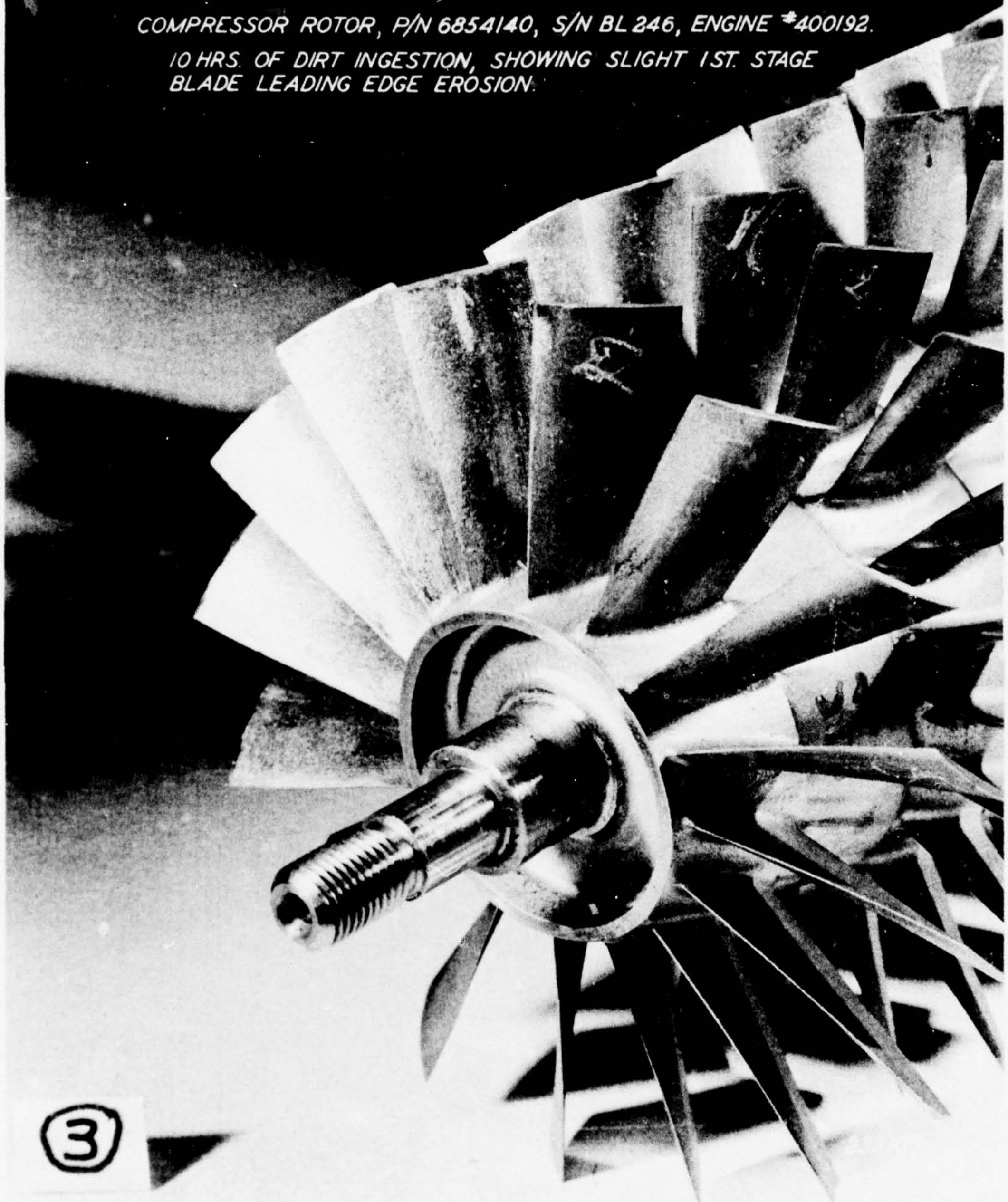

COMPRESSOR ROTOR, P/N 6854140, S/N BL 246, ENGINE #400192.
10 HRS. OF DIRT INGESTION, SHOWING SLIGHT 1ST. STAGE BLADE LEADING EDGE EROSION.
3

Figure 6

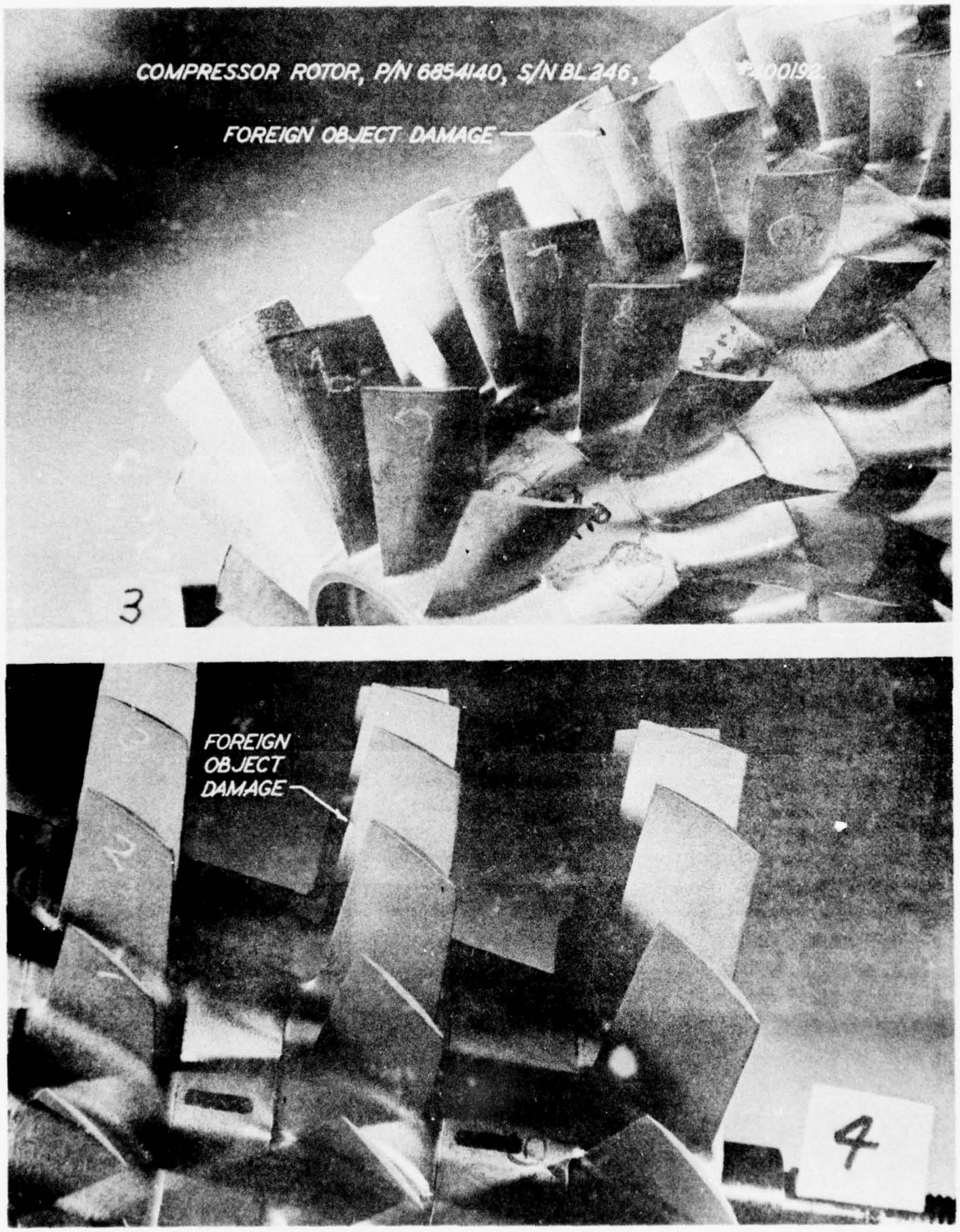

COMPRESSOR ROTOR, P/N 6854140, S/N BL246,
FOREIGN OBJECT DAMAGE
3
FOREIGN
OBJECT
DAMAGE
4

Figure 7

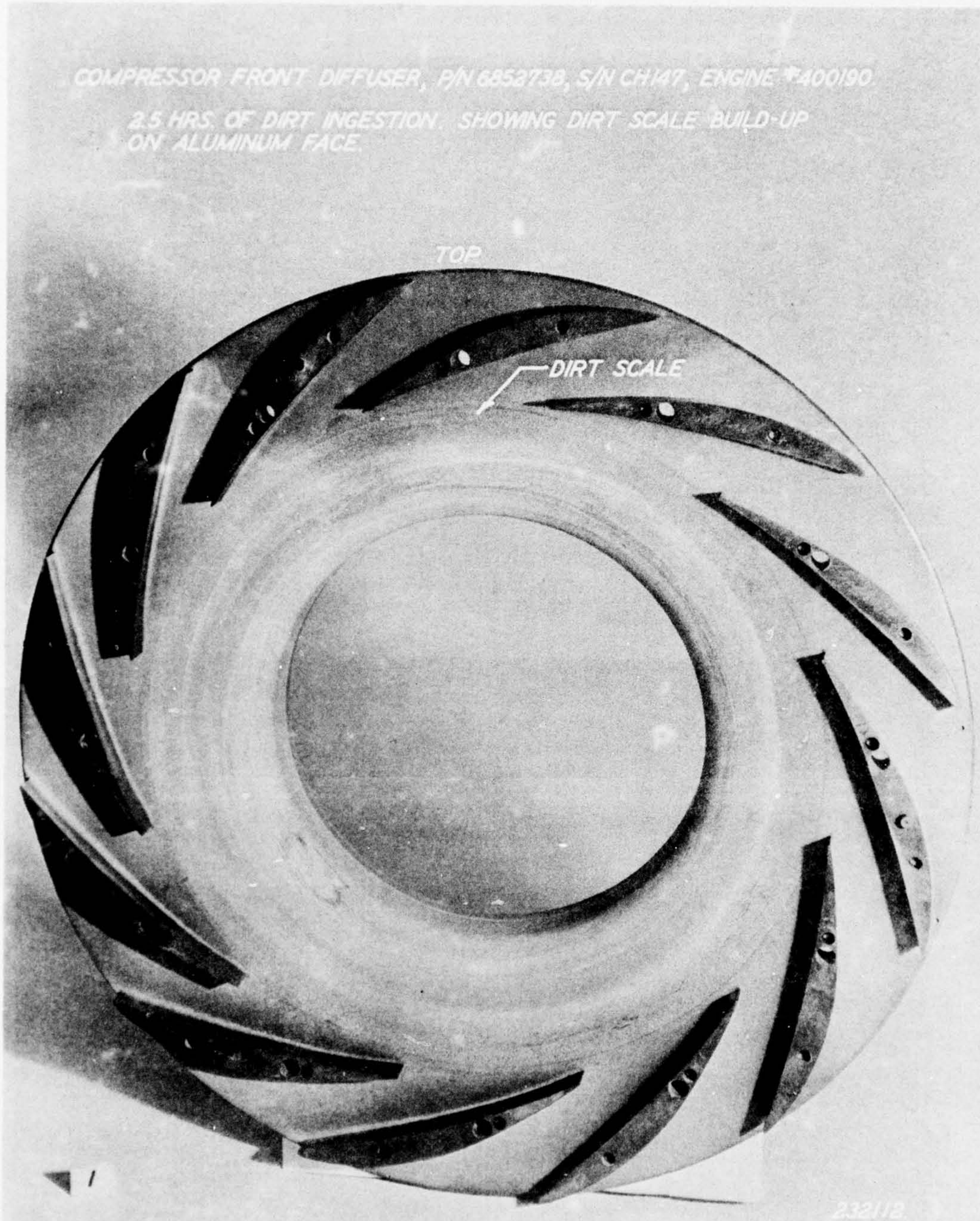

COMPRESSOR FRONT DIFFUSER, P/N 6852738, S/N CH147, ENGINE #400190.
2.5 HRS. OF DIRT INGESTION. SHOWING DIRT SCALE BUILD-UP ON ALUMINUM FACE.
TOP
DIRT SCALE
232112

Figure 8

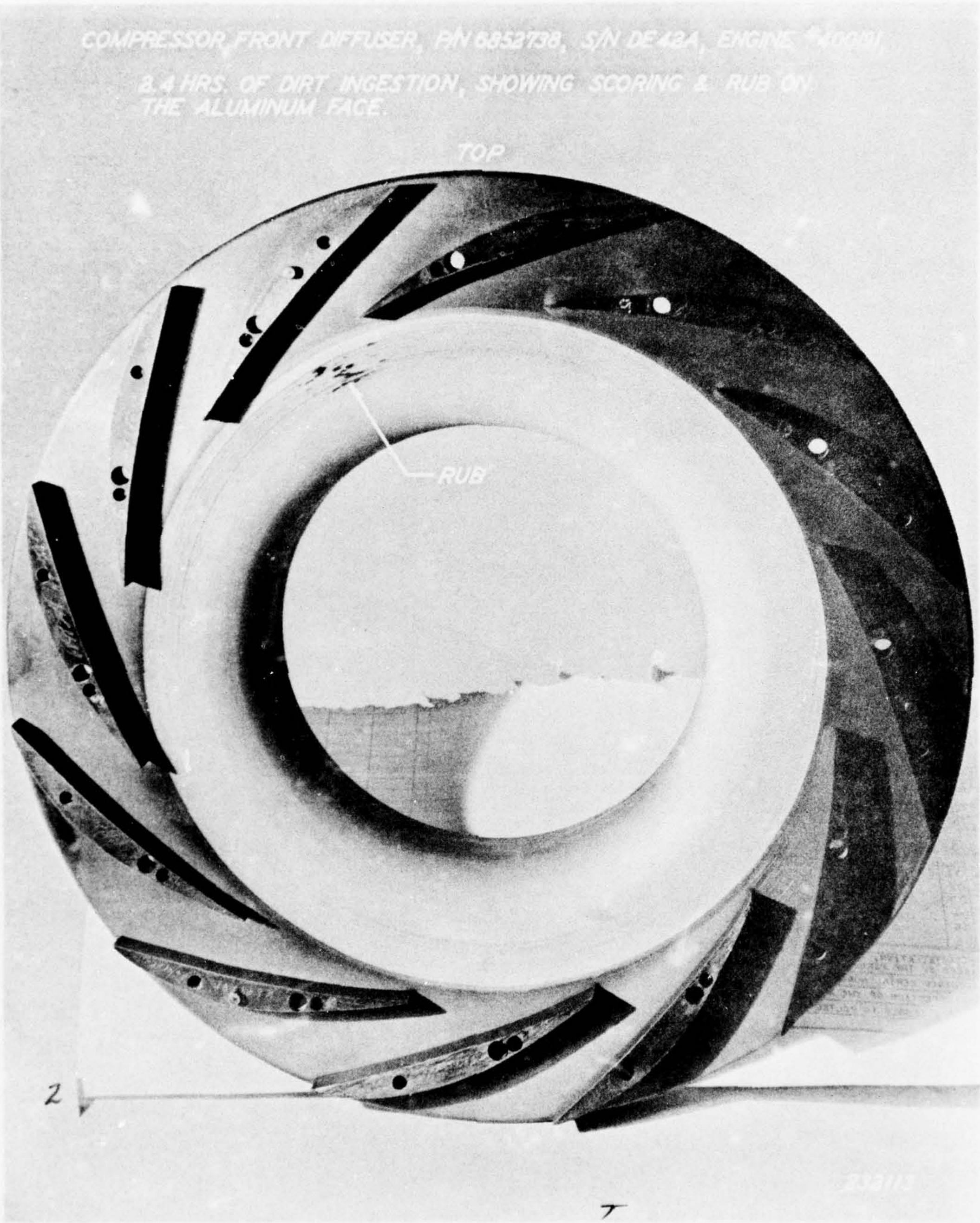

COMPRESSOR FRONT DIFFUSER, P/N 6852738, S/N DE42A, ENGINE #10011
8.4 HRS. OF DIRT INGESTION, SHOWING SCORING & RUB ON THE ALUMINUM FACE.
TOP
RUB

Figure 9

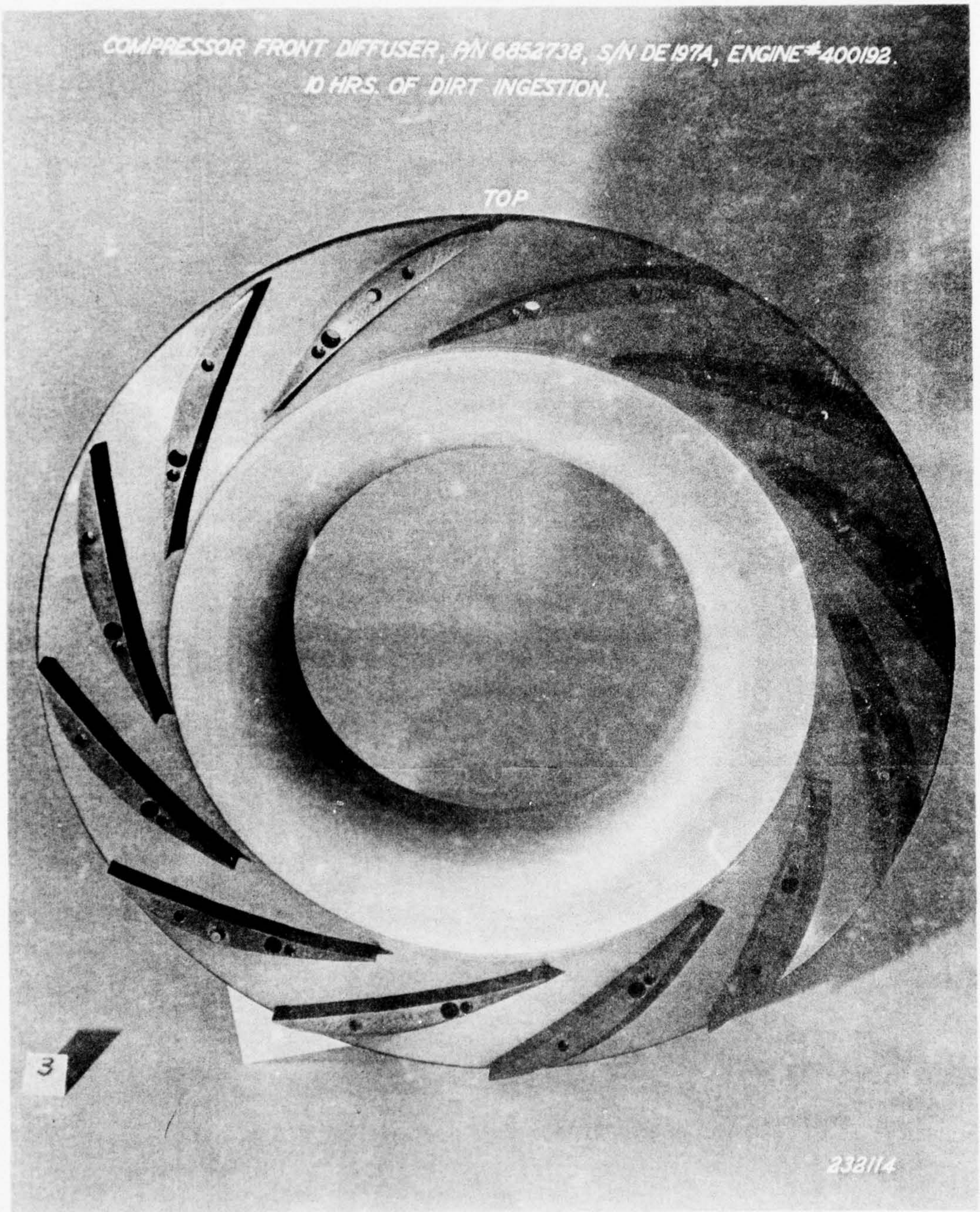

COMPRESSOR FRONT DIFFUSER, P/N 6852738, S/N DE 197A, ENGINE #400192.
10 HRS. OF DIRT INGESTION.
TOP
3
238114

Figure 10

e. Rear Diffuser.

(1) The Barrier Filter engine showed a slight sand blast effect on the face.

(2) The rear diffusers of both Particle Separator engines showed no visible signs of wear.

f. Diffuser Scroll.

(1) The scroll inner surface of the Barrier Filter engine showed a slight sand blast effect (the sensing tubes were sand blasted over one-half of the circumference). The Particle Separator engine showed a slight polishing effect on the sensing tubes.

(2) Wear and erosion were not visible on the diffuser scroll of the 10-hour Particle Separator engine.

g. Compressor Discharge Tube. Fine powder had accumulated on the inside of the tubes of all three test engines.

h. Compressor Front and Rear Bearings and Front Support. There were no visible indications of wear and erosion on the three test engines.

2.2.3.2.2. Turbine Section.

a. First-Stage Nozzle Fireshield.

(1) The Barrier Filter engine heat shield was very dirty with a slight amount of silicone (glass) adhered to the shield.

(2) Both Particle Separator engine heat shields showed some evidence of dirt impingement and slight dust accumulation on the forward face of the heat shield.

b. First-Stage Nozzle.

(1) The Barrier Filter engine showed a concentration of dirt on the outer and inner bands and some dirt impingement on the vanes.

(2) The first-stage nozzle of both Particle Separator engines revealed a light dirt accumulation on the outer and inner bands.

c. First-Stage Wheel.

(1) The Barrier Filter engine showed a collection of dirt on both sides of the wheel under the rim and edges of the balance ring. Dirt adhered to both sides of the blades and was heaviest on the top trailing edges (figure 11). The Particle Separator engine showed some dirt collection under the wheel rim and a slight dirt accumulation on the top side of the blades (figure 12).

(2) The 10-hour Particle Separator engine showed a slight accumulation of dirt under the rim on both sides of the wheel as well as evidence of dirt impingement on the lower half of the top of the blades (figure 13).

d. Second-Stage Nozzle.

(1) The Barrier Filter engine showed an accumulation of dirt behind the trailing edge of the vanes on the outer supporting surface. There was evidence of dirt impingement on the vanes.

(2) Both Particle Separator engines showed a very light dirt accumulation at the trailing edge of the vanes in the hub area.

e. Second-Stage Wheel.

(1) The Barrier Filter engine showed heavy dirt accumulation on the blades and blade bases and heavy dirt deposits under the wheel rim (figure 14).

(2) Both Particle Separator engines showed dirt accumulation similar to that found in the Barrier Filter engine, but to a lesser degree (figures 15 and 16).

f. Power Turbine Support.

(1) The balance piston, nickel-graphite air seal of the Barrier Filter engine showed erosion in the entire circumference (figure 17). The average change in radial clearance owing to erosion of seal material was 0.008 inch (figure 16, appendix I, section 3). The

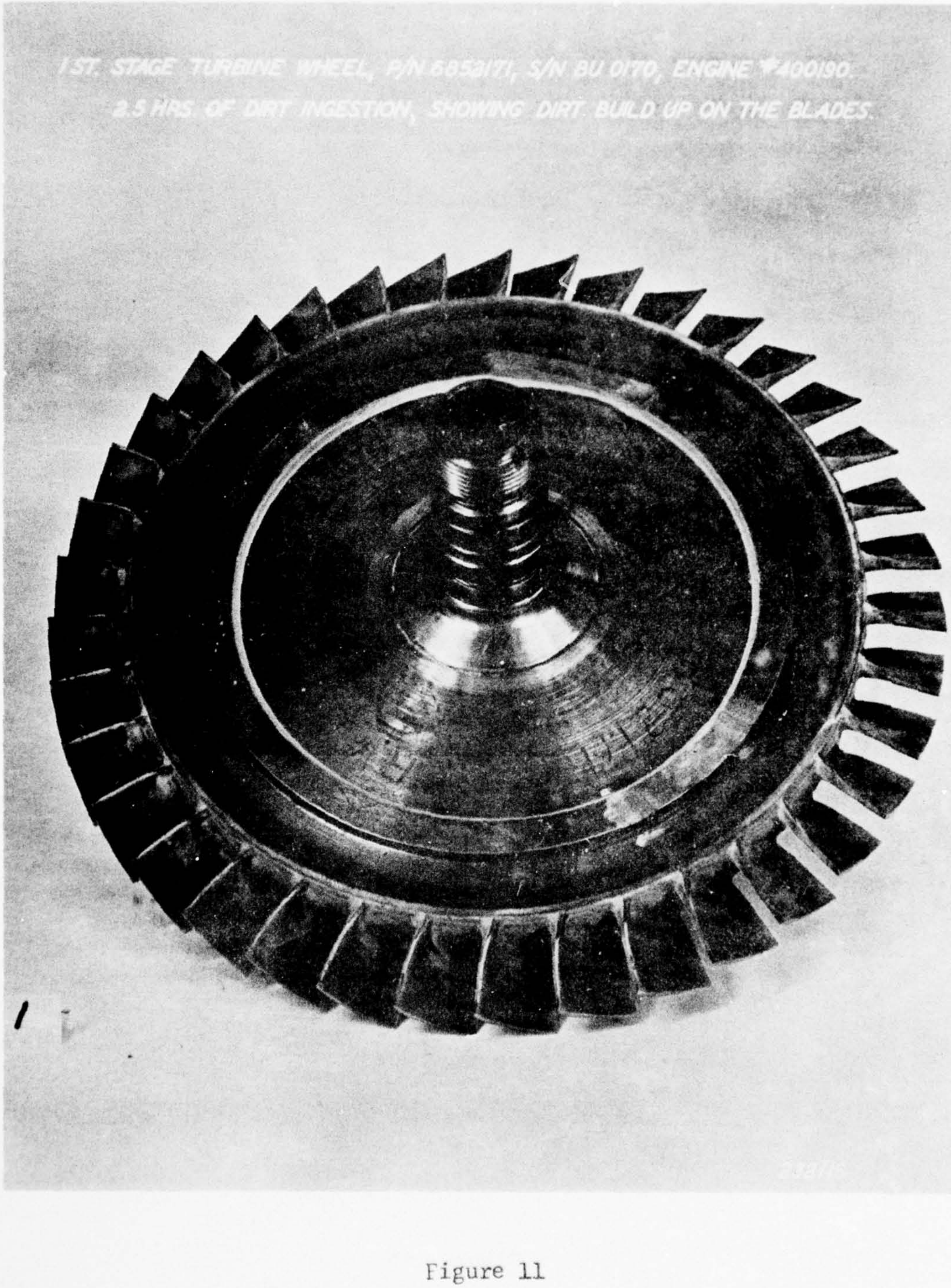
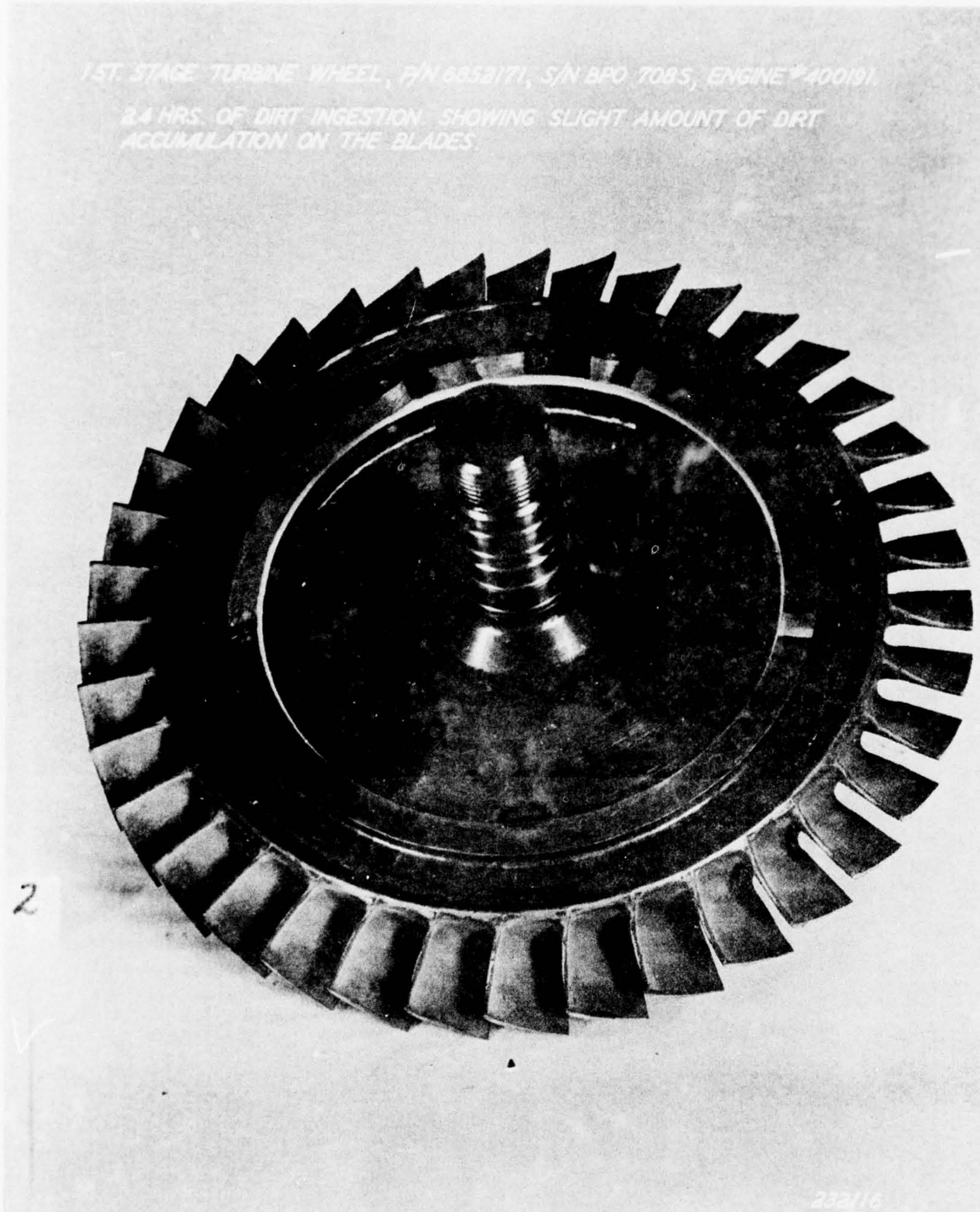

1ST. STAGE TURBINE WHEEL, P/N 6853171, S/N BU 0170, ENGINE #400190.
2.5 HRS. OF DIRT INGESTION, SHOWING DIRT BUILD UP ON THE BLADES.

Figure 11


1ST. STAGE TURBINE WHEEL, P/N 6852171, S/N BPO 708S, ENGINE # 400191.
2.4 HRS. OF DIRT INGESTION. SHOWING SLIGHT AMOUNT OF DIRT ACCUMULATION ON THE BLADES.
232116

2

Figure 12

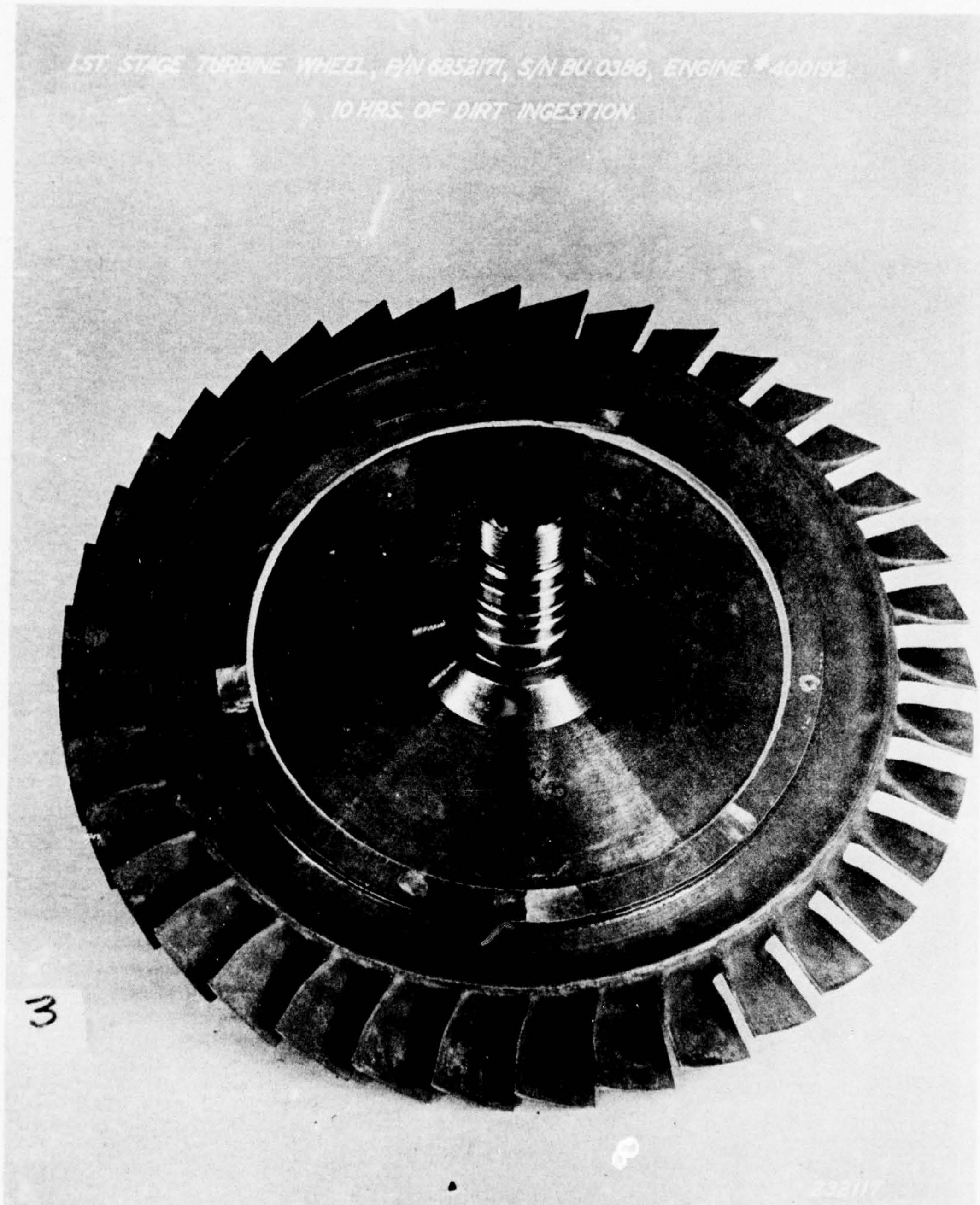

1ST. STAGE TURBINE WHEEL, P/N 6852171, S/N BU 0386, ENGINE #400192.
10 HRS. OF DIRT INGESTION.
3

Figure 13

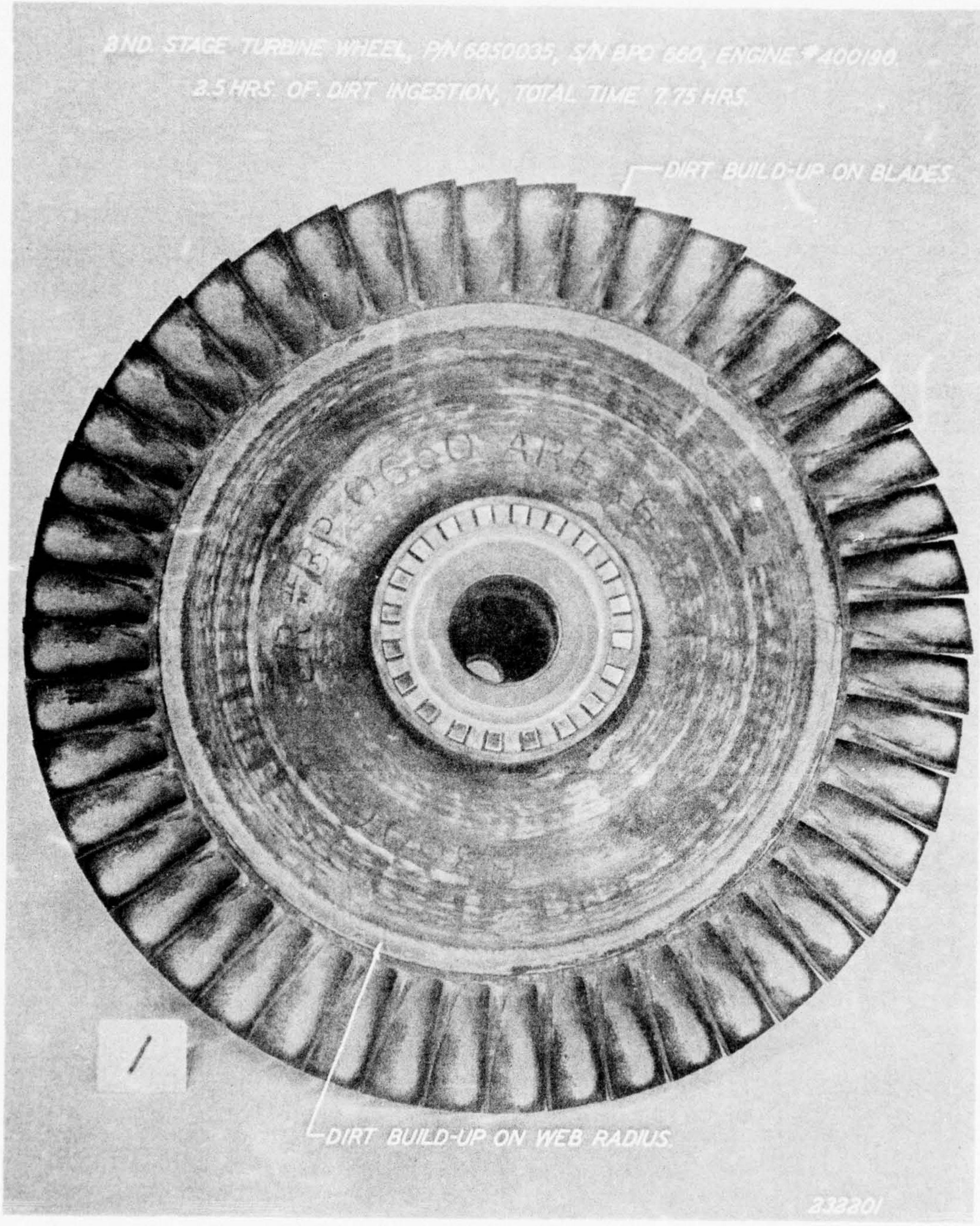

2ND. STAGE TURBINE WHEEL, P/N 6850035, S/N BPO 660, ENGINE #400190.
3.5 HRS. OF. DIRT INGESTION, TOTAL TIME 7.75 HRS.
DIRT BUILD-UP ON BLADES.
DIRT BUILD-UP ON WEB RADIUS.
232201

Figure 14

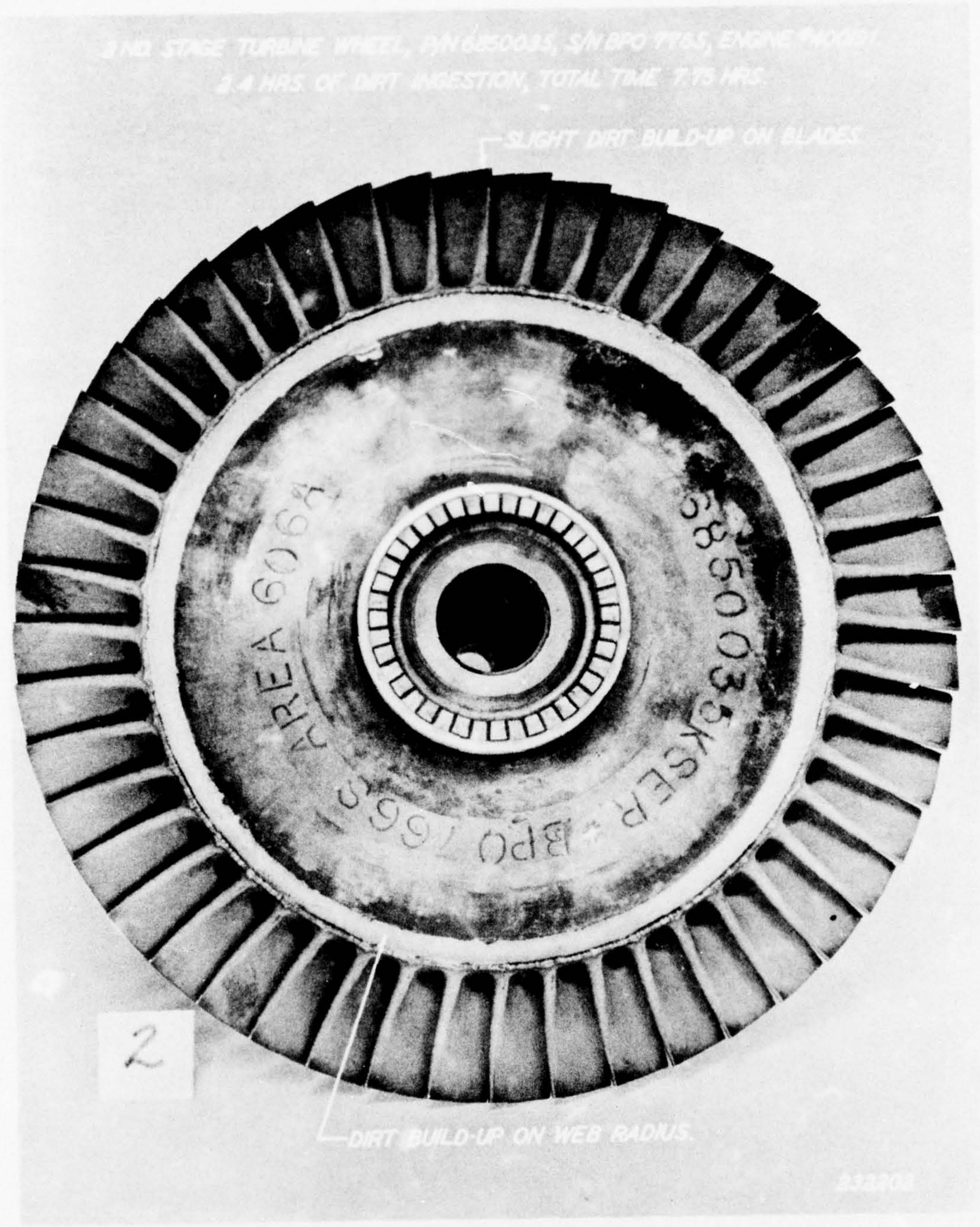

2 NO. STAGE TURBINE WHEEL, P/N 6850035, S/N BPO 7765, ENGINE
2.4 HRS. OF DIRT INGESTION, TOTAL TIME 7.75 HRS.
SLIGHT DIRT BUILD-UP ON BLADES.
2
DIRT BUILD-UP ON WEB RADIUS.

Figure 15

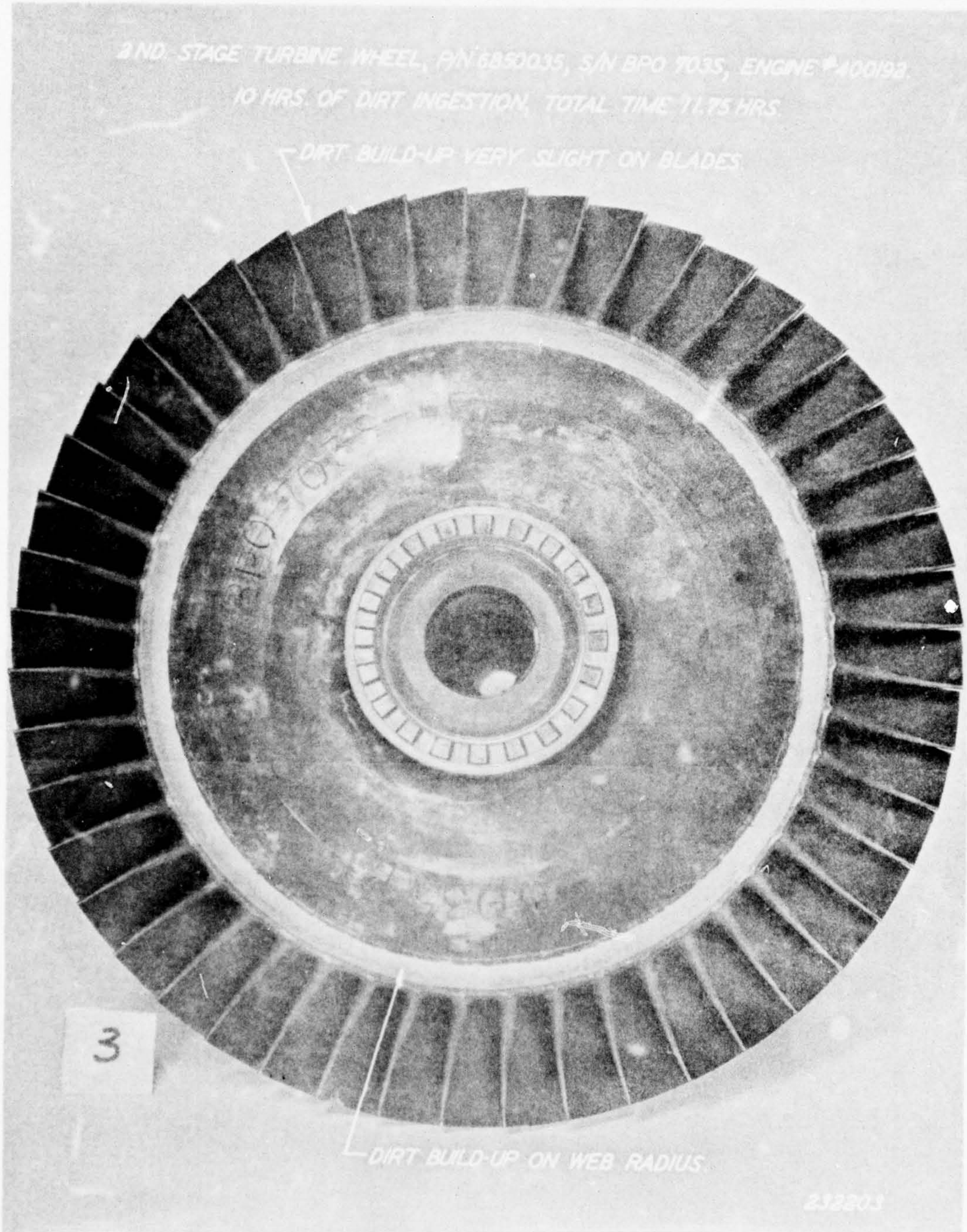

2ND. STAGE TURBINE WHEEL, P/N 6850035, S/N BPO 7035, ENGINE # 400198.
10 HRS. OF DIRT INGESTION, TOTAL TIME 11.75 HRS.
DIRT BUILD-UP VERY SLIGHT ON BLADES.
3
DIRT BUILD-UP ON WEB RADIUS.
232203

Figure 16

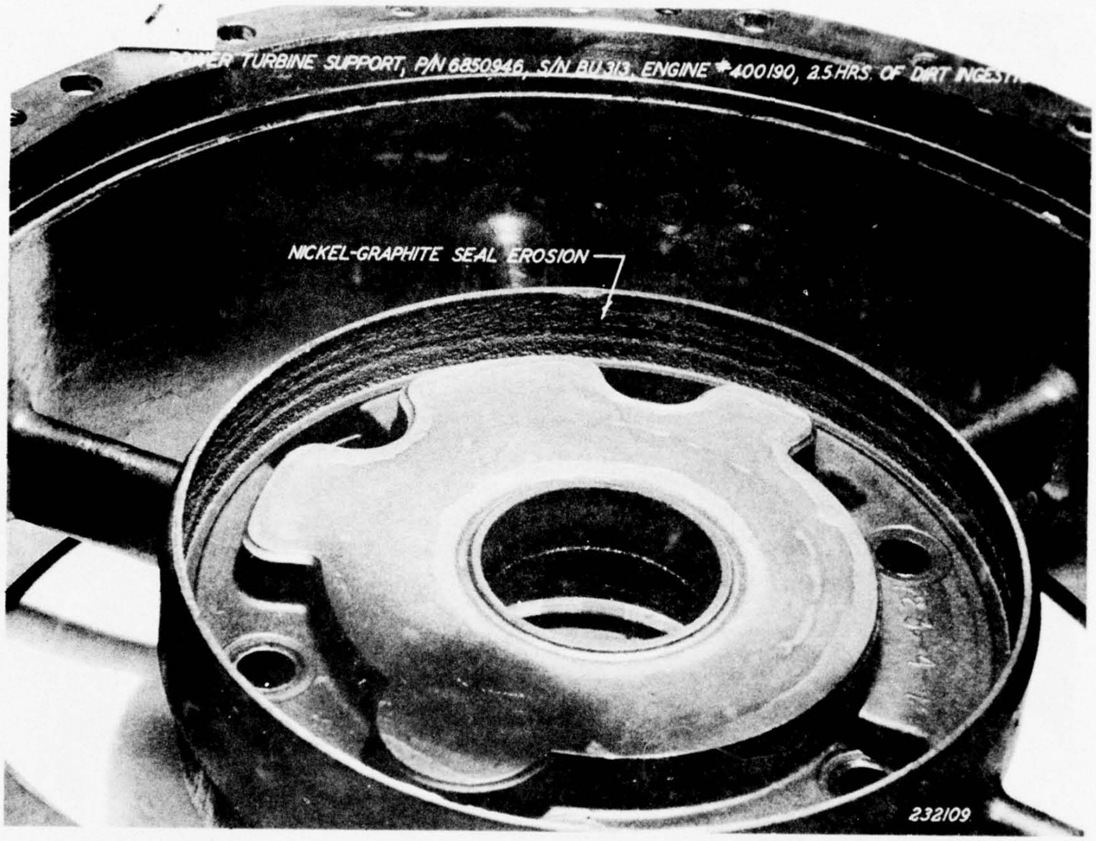

TURBINE SUPPORT, P/N 6850946, S/N BU313, ENGINE *400190, 2.5 HRS. OF DIRT
NICKEL-GRAPHITE SEAL EROSION
232109

Figure 17

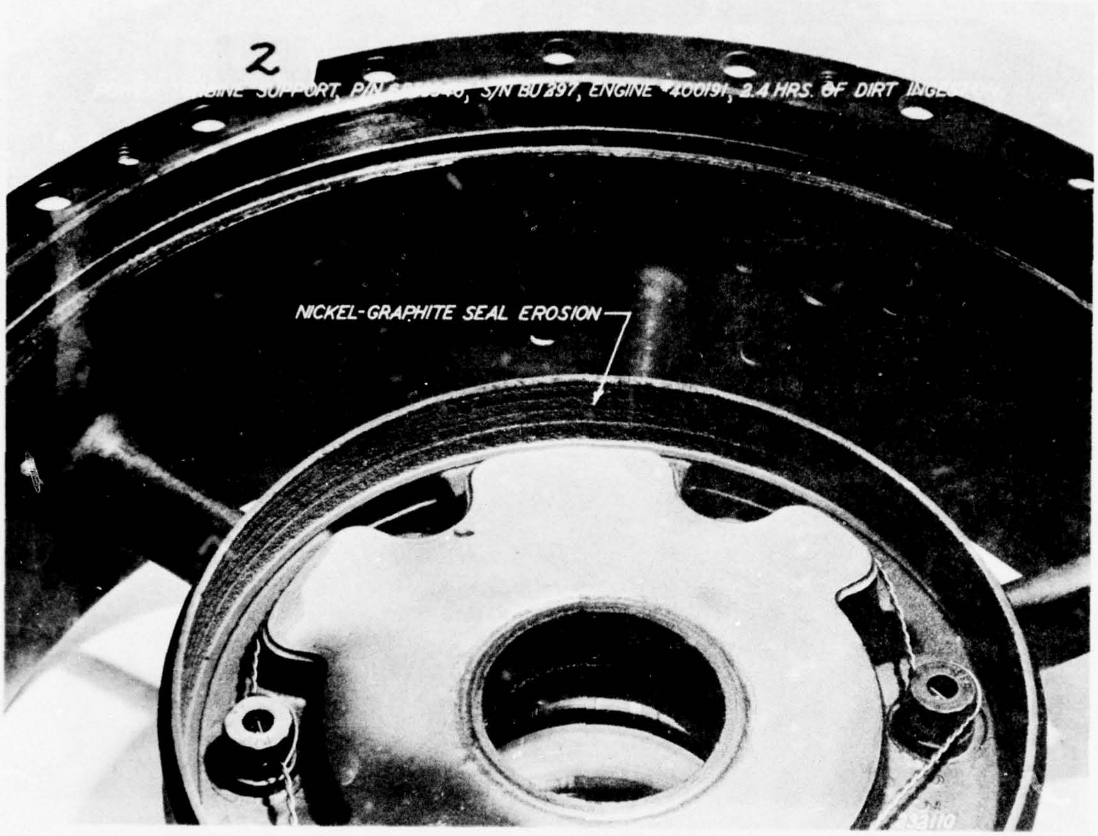


Figure 18

Particle Separator engine showed less visual erosion to the air seal (figure 18), the change in radial clearance owing to erosion of seal material averaging 0.002 inch (figure 16, appendix I, section 3).

(2) The 10-hour Particle Separator engine showed slight visual erosion in the circumference of the seal (figure 19). The average change in radial clearance owing to erosion of seal material was 0.0016 inch (figure 16, appendix I, section 3).

g. Third-Stage Nozzle. There was no visible evidence of wear and erosion on the three test engines.

h. Third-Stage Wheel. All three test engines showed a slight dirt accumulation on the trailing rim.

i. Fourth-Stage Nozzle. Wear and erosion were not visible on the three test engines.

j. Fourth-Stage Wheel. There was a slight dirt accumulation on the trailing rim on all three test engines.

k. Tiebolt. No wear or erosion was evident on the three test engines.

(1) Power Turbine Shaft.

(a) The Barrier Filter engine showed an oil coke build-up on the shaft.

(b) There was no visible evidence of wear and erosion on either Particle Separator engine.

2.2.3.2.3. Combustion Section.

a. Outer Combustion Case. No signs of wear or erosion were visible on the three test engines.

b. Combustion Liner.

(1) The Barrier Filter engine liner exhibited a residue build-up composed of partially burned foreign matter on the inside diameter at the four and ten o'clock positions (figure 20).

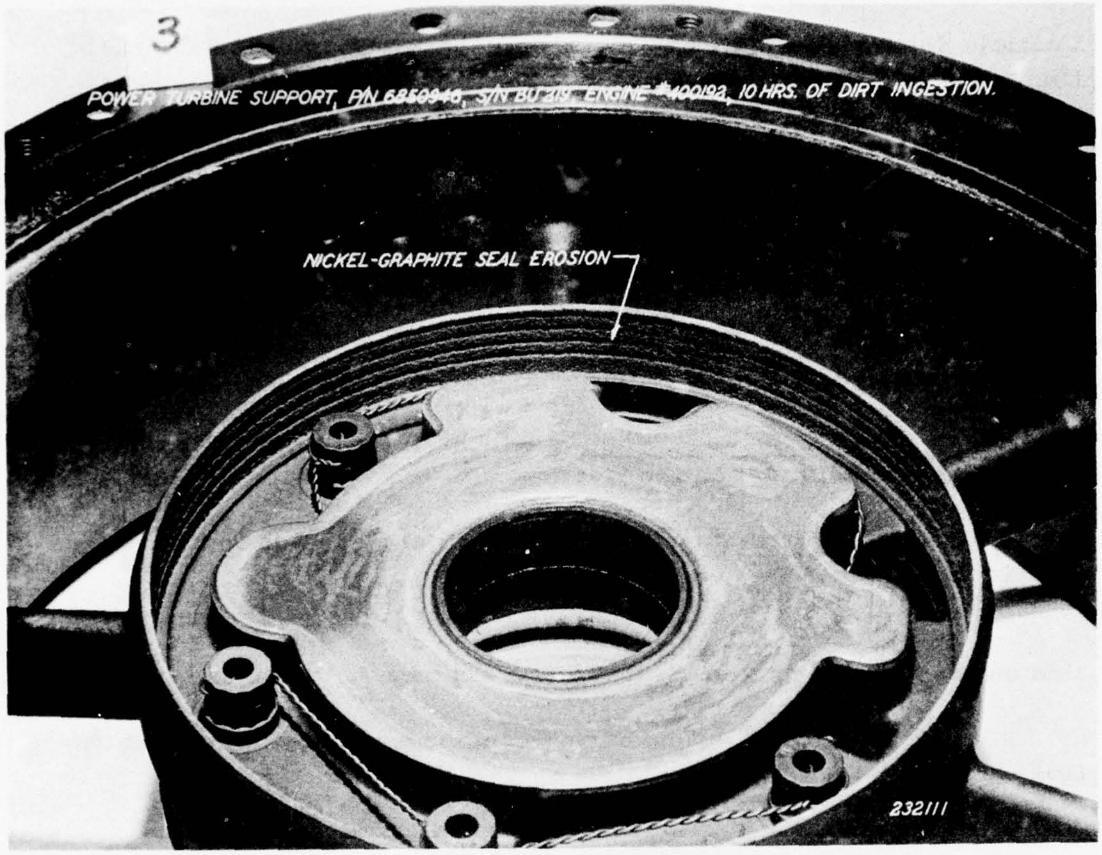

3
POWER TURBINE SUPPORT, P/N 6850946, S/N BU 219, ENGINE #400192, 10 HRS. OF DIRT INGESTION.
NICKEL-GRAPHITE SEAL EROSION
232111

Figure 19

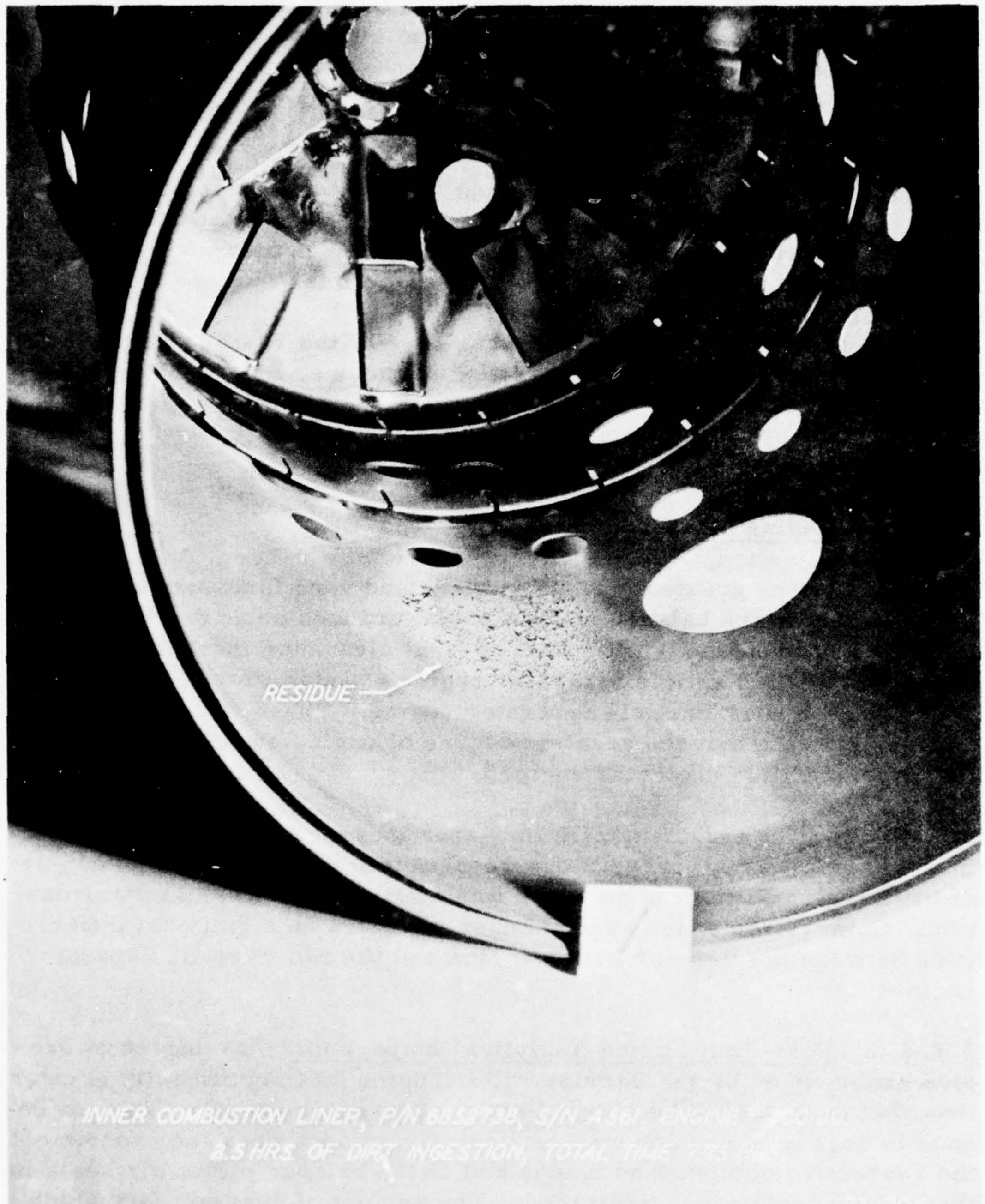

RESIDUE
INNER COMBUSTION LINER,
2.5 HRS. OF DIRT INGESTION, TOTAL TIME

Figure 20

(2) The combustion liners of both Particle Separator engines were in good condition, showing no signs of wear and erosion (figures 21 and 22).

c. Gas-Producer Support.

(1) The No. 8 bearing bore of the Barrier Filter engine was slightly fretted at the one, four, and seven o'clock positions. The Particle Separator engine showed heavy fretting in the No. 8 bearing bore at the one, four, and seven o'clock positions.

(2) The No. 8 bearing bore of the 10-hour Particle Separator engine showed slight fretting at the one, four, and seven o'clock positions.

2.2.4. Analysis.

2.2.4.1. Engine Measurements.

2.2.4.1.1. The greatest change in blade and vane fundamental frequencies and in the balance piston seal clearances occurred in the Barrier Filter engine. The wheel-to-seal clearance increased two times that of the Particle Separator engine and five times that of the 10-hour Particle Separator engine. These changes indicate that the greatest degree of engine erosion occurred in the Barrier Filter protected engine.

2.2.4.1.2. The turbine nozzle flow area measurements showed an increase in all areas except for a reduction in the second-stage nozzle of the Barrier Filter engine which was attributed to thermal deformation. Comparison of the area changes indicates no significant difference between the Barrier Filter engine and the two Particle Separator engines.

2.2.4.2. Post-Test Engine Analytical Inspection. The degree of erosion experienced by the Barrier Filter engine was significantly greater than that experienced by either Particle Separator engine. This difference in degree of erosion was particularly evident when the erosion of the respective compressor blades and of the balance piston air seals in the turbine section was compared. The amount of dust and dirt which had accumulated on various parts of the engines showed that more efficient filtration was afforded by the Particle Separator than the Barrier Filter.

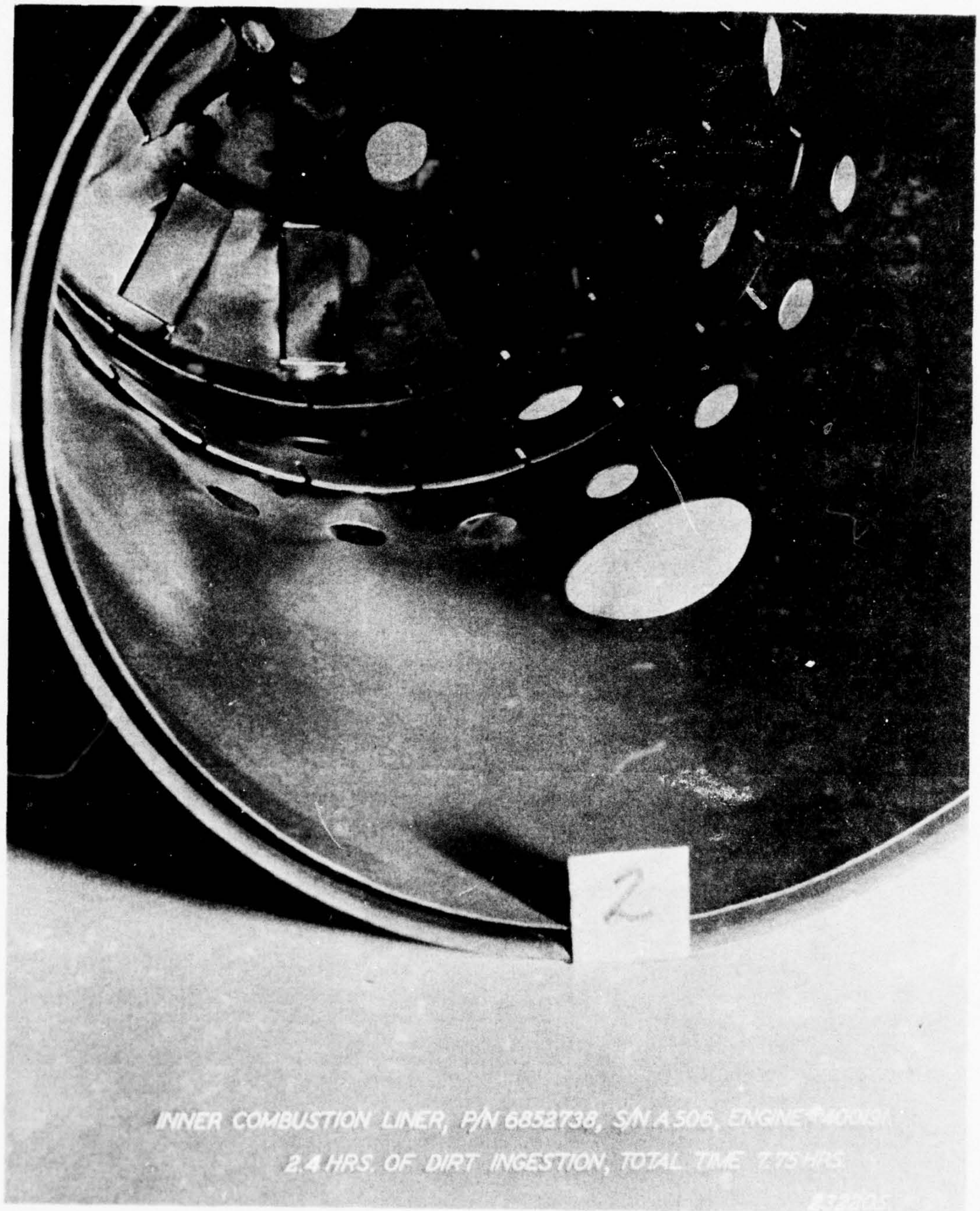

2
INNER COMBUSTION LINER, P/N 6852738, S/N A506,
2.4 HRS. OF DIRT INGESTION, TOTAL TIME 7.75 HRS.

Figure 21

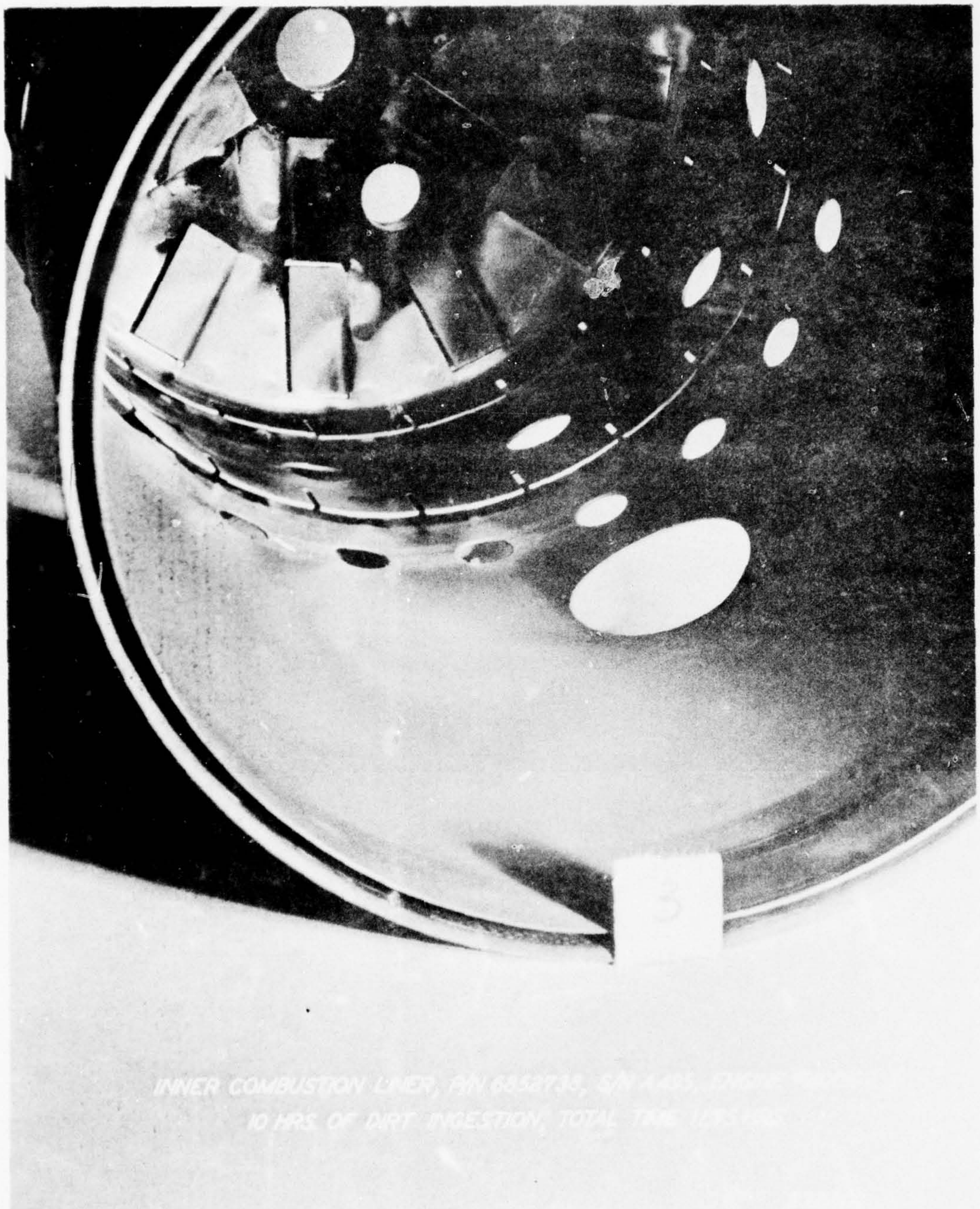

INNER COMBUSTION LINER, P/N
10 HRS. OF DIRT INGESTION, TOTAL TIME

Figure 22

2.3. ENGINE PERFORMANCE DEGRADATION.

2.3.1. Objective.

To determine the amount and rate of engine performance degradation resulting from ingestion of foreign objects.

2.3.2. Technique.

2.3.2.1. Engine Performance Measurements.

2.3.2.1.1. Prior to the tests described in paragraphs 2.3.2.2 through 2.3.2.5, the engine manufacturer conducted a standard performance calibration on three new T63-A-5A engines. After completion of the tests, the engines were returned to the manufacturer and another calibration was performed. USAAVNTBD personnel analyzed and compared the results of these calibrations.

2.3.2.1.2. Supplemental engine performance data were compiled from helicopter-installed engine instrument readings collected by project personnel during each flight. Graphs depicting the changes in engine performance parameters were prepared.

2.3.2.2. Sand and Dust.

2.3.2.2.1. The two test YOH-6A Helicopters, equipped with calibrated engines, were flown at a gross weight of 2,500 pounds side by side in a preselected dust and sand environment at Yuma Proving Ground, Arizona. To maintain an equal ingestion environment, the helicopters were programmed to hover over a dust silt surface for a period of 10 minutes headed into the wind, laterally separated by a distance of 25 feet or more. Both helicopters were to land and to reduce power to "idle" setting for three minutes, and then to fly to a nearby sandy surface and repeat a similar 13-minute cycle for a total mission time of 26 minutes. If, at any time, either helicopter was unable to continue hovering due to maintenance requirements or to engine deterioration, the flight was to be terminated.

2.3.2.2.2. One test helicopter with a new calibrated engine installed and a Particle Separator protective device (engine S/N 400192) was subjected to 10 hours of hovering, equally divided between sand and dust environments.

Figure 23. The OH-6A Helicopters, with protective systems installed, hovering over sand surface.

Figure 24. The OH-6A, with protective system installed, hovering in water spray.

2.3.2.3. Grass and Hay. The two test helicopters were operated over a surface covered with hay, using the 13-minute cycle and control criteria outlined in paragraph 2.3.2.2.1.

2.3.2.4. Moisture. The helicopter with the Barrier Filter installed was hovered for four minutes in a dust environment, during which time the Δp reached the maximum limit. The helicopter was then hovered in a water spray for 10 minutes. The same process was followed with the helicopter on which the Particle Separator was installed (engine S/N 400191). With a clean filter element installed, the Barrier Filter helicopter was hovered in water spray for 10 minutes and then hovered in dry air until the Δp stabilized. Again, this procedure was duplicated by the Particle Separator helicopter in order to keep the engine environmental exposure equal. (See figure 24.)

2.3.2.5. General. The sand, dust, and hay subtests were accomplished at an approximate five-foot skid height hover. Pertinent engine and atmospheric data were recorded during each flight. At least two engine power checks and two acceleration-deceleration checks were performed for each flight, and particular attention was given to the detection of engine deterioration. The Δp across each test device was monitored by means of a gauge mounted on the respective helicopter instrument panel. The maximum ("do not exceed") value of Δp was stipulated by the LOH Project Manager to be 5.6 inches of water. This value represented a nominal two-inch increase above the pressure differential value obtained with a clean Barrier Filter. Before and after each flight, the filter element in the Barrier Filter was weighed to determine the amount of foreign material collected. Following weighing, the Barrier Filter element and the engine plenum chambers in both aircraft were carefully cleaned with a vacuum cleaner, and the contents were kept separate and appropriately identified. The vacuum cleaner bags with their contents were delivered to the engine manufacturer who prepared an analysis of the composition and micron size of each collection. The Barrier Filter element was again weighed after it was cleaned to determine if any foreign material remained. Oil samples from the engine and transmission of each helicopter were taken daily.

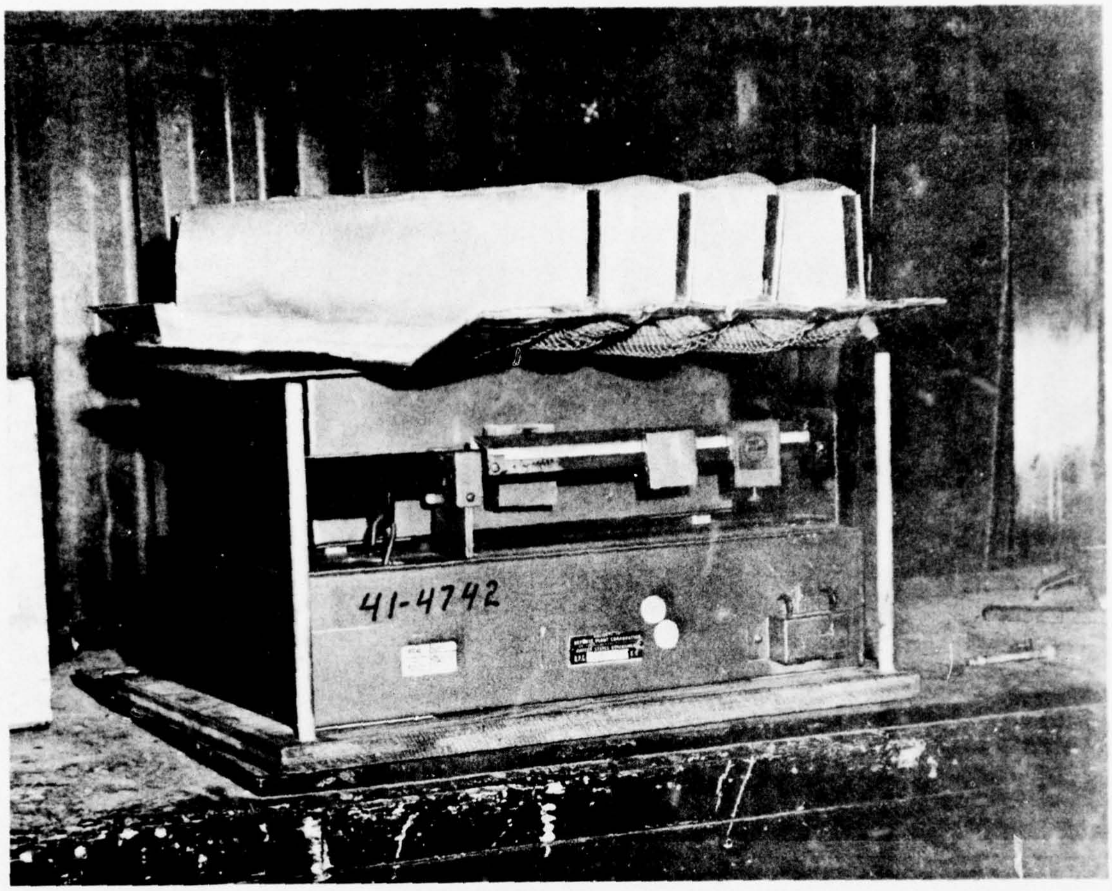


Figure 25. The Barrier Filter element was weighed before and after each flight.

Figure 26. Collecting samples from Barrier Filter element after hover in sand and dust environment.

2.3.3. Results.

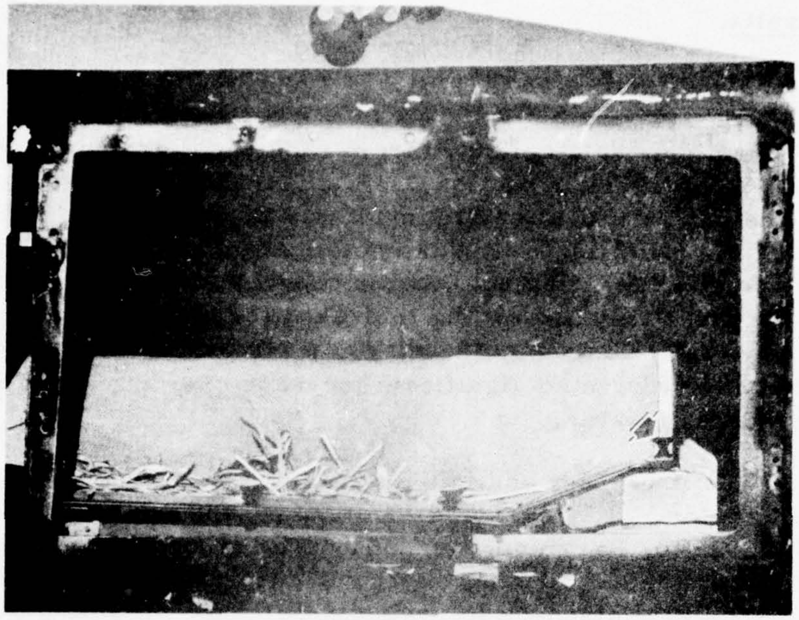
2.3.3.1. Sand and Dust.

2.3.3.1.1. Pertinent data collected from each flight are contained in figures 1 and 2, appendix I, section 3. Each of eight side-by-side flights into the sand and dust environment was terminated prior to completion of the programmed 26-minute cycle (paragraph 2.3.2.1) because the Barrier Filter element became congested with sand and dust sufficiently to cause the Δp reading to exceed the allowable limit of 5.6 inches of water. The corresponding Δp reading in the Particle Separator helicopter gave no significant increase over the baseline Δp of 4.0 inches of water.

2.3.3.1.2. When the hover and idle operation in dust, sand, hay, and water reached a total of 2 hours and 27 minutes, the exhaust gas temperature (EGT) in the Barrier Filter helicopter reached the maximum allowable limit of 1380°F. during the power check prior to the next takeoff. An acceleration check following power check resulted in a popping noise from the engine, a characteristic of compressor stall. This condition also prevailed with the filter element removed. The comparative portion of the test was terminated at this time on the basis of significant engine deterioration being evidenced in the Barrier Filter helicopter.

2.3.3.1.3. Analyses of the composition and micron size of sand and dust collections obtained from the used Barrier Filter element and plenum chambers of both helicopters are contained in figures 11 through 15, appendix I, section 3. Particles with the average size of 85 microns (dust) to 100 microns (sand) and maximum size of 350 microns (sand) passed through the Barrier Filter to the plenum chamber. Samples taken from the plenum chamber of the Particle-Separator-equipped helicopter were too small to analyze. Oil sample analyses (figures 1 and 2, appendix I, section 3) revealed that the silicon content for all three engines was the same.

2.3.3.2. Grass and Hay. Pertinent data collected from hovering flights in areas strewn with hay are contained in appendix I, section 3.



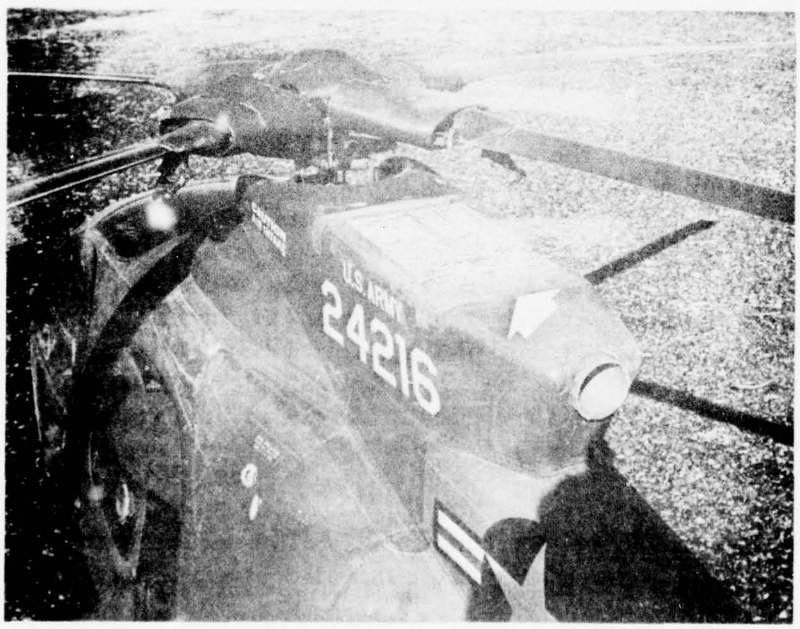


Figure 27. View of Barrier Filter (above) and air intake screen of Particle Separator (below) on OH-6A after hover in hay environment.

2.3.3.2.1. The Barrier Filter became clogged with hay and the Δp limit was reached after a total of 38 minutes of hovering. Most of the hay was removed from the filter by removing the element and shaking off the hay; however, some particles of hay were imbedded in the element under the protective screen and could not be removed by shaking or washing.

2.3.3.2.2. The screen which covered the intake of the Particle Separator became clogged with hay and caused the Δp to exceed the limit of 5.6 inches of water after both helicopters had hovered over the hay for four minutes and five seconds. After the hay was brushed off by hand from the Particle Separator intake screen, hovering operation was resumed, and the screen again became blocked after 13 minutes and 30 seconds. The variance in time was attributed to the difference in hay concentration. Another hover period of 10 minutes and 30 seconds had similar results. A flight at cruising speed was made in an attempt to determine if the airstream would remove the accumulated hay from the screen. Not all of the hay was removed; however, the Δp dropped from 5.6 to 4.6 inches of water during the five-minute flight. Post-flight inspection revealed that some hay passed through the Particle Separator, and collected on the engine bellmouth screen.

2.3.3.3. <u>Moisture</u>. Pertinent data collected from hovering flight in a water spray are contained in appendix I, section 3.

2.3.3.3.1. Water spray on a Barrier Filter which had been exposed to four minutes of hovering in dust caused the Δp to increase from 5.6 inches of water to a maximum of 8 inches of water in 10 minutes. A stabilized Δp of 7.8 inches of water was attained after 10 minutes of hovering. Water spray on an unused Barrier Filter element which had not been exposed to dust caused the Δp to increase from 3.4 inches of water to a stabilized 4.9 inches of water. After seven minutes of hover in dry air, Δp decreased to 3.9 inches of water.

2.3.3.3.2. The Particle Separator did not show visible effects from the water spray. Hover in water spray had no measurable effect on the Δp reading of the Particle Separator helicopter.

2.3.3.4. <u>Engine Performance Measurements</u>.

2.3.3.4.1. The results of the manufacturer's engine performance calibrations which were made before and after the tests are contained

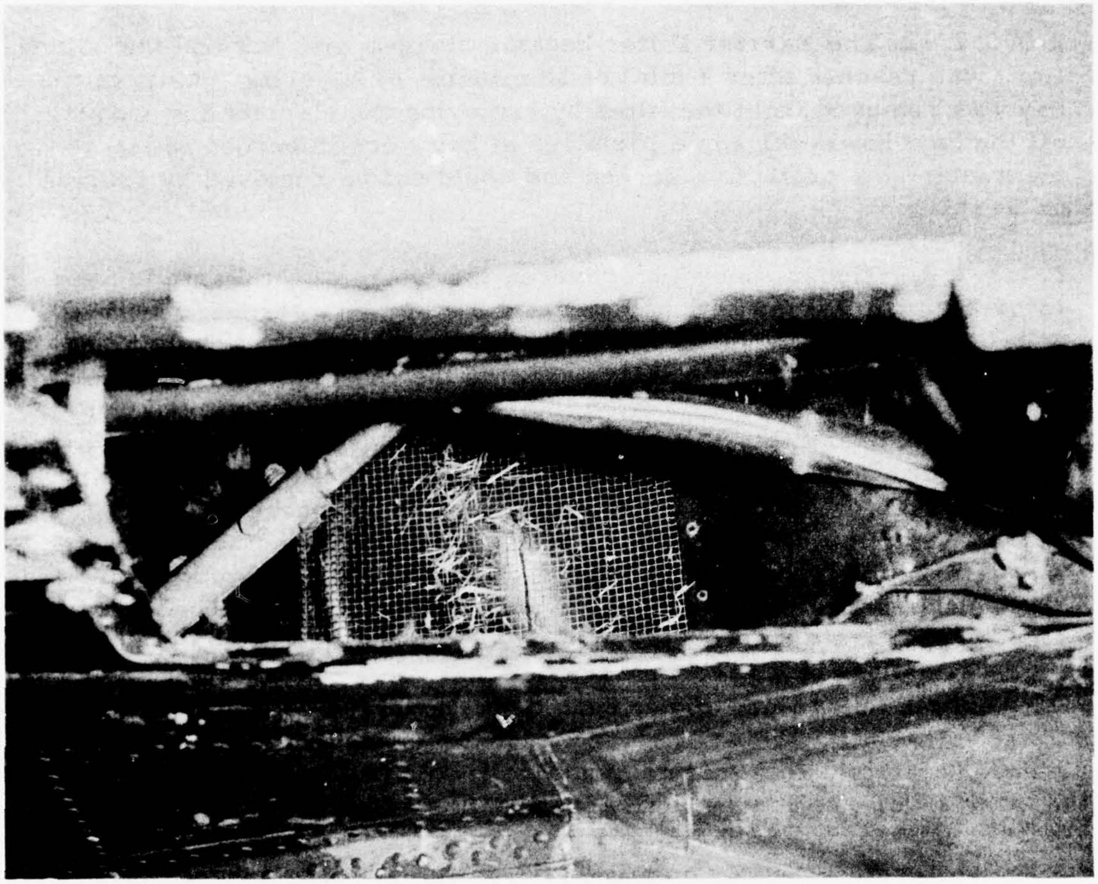


Figure 28. View of the engine bellmouth screen showing particles of hay which passed through the Particle Separator system during hover over loose hay.

in figure 20 through 22, appendix I, section 3. The greatest percentage of performance depreciation as a result of ingestion of foreign material occurred in the Barrier Filter engine. Shaft horsepower decreased and specific fuel consumption increased beyond specification limits (figure 20, appendix I, section 3). The engines employing the Particle Separator experienced a lesser depreciation in performance which remained within the specification limits (figures 21 and 22, appendix I, section 3).

2.3.3.4.2. Engine performance curves compiled from engine data collected during flight are contained in figures 3 through 8, appendix I, section 3. Comparison of these curves verified that the performance of the Barrier Filter engine depreciated to a greater degree than that of either of the Particle Separator engines. This performance depreciation is illustrated by the greater rise in referred turbine outlet temperature (TOT) and referred fuel flow rate.

2.3.4. Analysis.

2.3.4.1. The T63-A-5A engine, which was protected from foreign object ingestion by the Particle Separator, suffered less performance degradation than a similar engine protected by the Barrier Filter.

2.3.4.2. The Particle Separator was superior to the Barrier Filter in protecting the engine from moisture impingement.

2.3.4.3. Neither system was completely satisfactory for hover operation in loose hay. The Barrier Filter endured a longer hover time before becoming clogged than the Particle Separator but was harder to clean. Straw particles were found on the engine intake protective screen below the Particle Separator following hover tests in hay, indicating incomplete protection. No hay passed through the Barrier Filter to the engine intake screen.

2.4. SERVICING REQUIREMENTS.

2.4.1. Objective.

To compare the servicing and maintenance requirements of the test items.

2.4.2. Technique.

The requirements for inspecting, servicing, and maintaining the two systems were determined and the man-hours expended for each were recorded and compared. The need for special tools for servicing and maintaining each system was determined. Throughout the test, attention was given to those features which contributed toward or detracted from the ease of maintenance and servicing of each system.

2.4.3. Results.

2.4.3.1. Maintenance and Servicing.

2.4.3.1.1. Barrier Filter. Before tests could be initiated, several man-hours were expended by the manufacturer's representative in custom-fitting each of four filter elements to the structure framework. The fitting was necessary because the holes in the filter element through which the plastic snap fasteners were inserted varied with respect to size and spacing. The holes were altered with a round file.

After the filter element was fitted to the structure, one man positioned and secured the element 12 times during the test. The time required for installation varied from a minimum of 12 minutes to a maximum of one hour and thirty minutes as a result of difficulties encountered with securing the element with the snap fasteners. One man removed the element 12 times in time periods varying from 30 seconds to 15 minutes. Pliers occasionally were required to remove some fasteners that fit too tightly to be removed by hand.

The filter element required washing and drying after exposure to dust or sand. Printed instructions were provided by the manufacturer and are included in appendix I, section 3. One man required 10 minutes to wash the element in accordance with the instructions. A period of 10 hours (over night) in a ventilated hangar was sufficient to dry the filter element. In one instance, a wet filter, after exposure to 2.5 hours of sunlight, was not completely dry, weighing 2.52 pounds compared with 2.3 pounds dry.

Preflight inspection consisted of determining that a clean filter element was in place and properly secured.

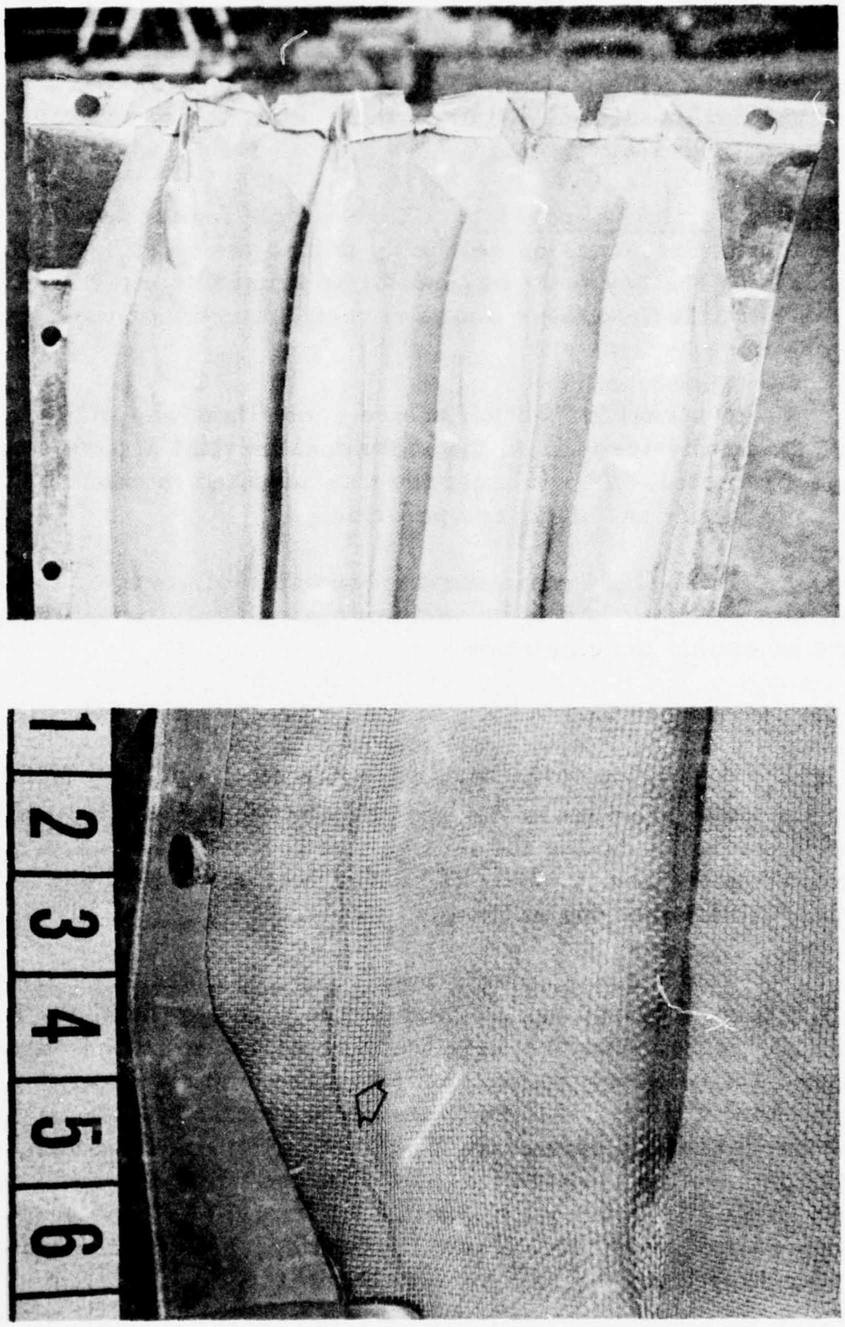


Figure 29. Damage sustained by Barrier Filter as a result of washing. Arrow in lower photograph shows deterioration and separation of filter materiel.

Post-flight maintenance consisted of removing the filter element, cleaning the plenum chamber with a vacuum cleaner to remove the considerable amount of accumulated dust and sand, and replacing with a clean element.

2.4.3.1.2. Particle Separator. The Particle Separator required no unscheduled maintenance or servicing during the sand, dust, or water tests. During the hay test, hay had to be brushed frequently by hand from the Particle Separator intake screen to restore adequate airflow to the engine.

A visual inspection before each flight was made to determine if the intake screen and the individual inertial separator tubes were unobstructed. The exhaust fan was actuated momentarily during preflight to verify satisfactory operation.

Post-flight maintenance consisted of visual inspections. The plenum chamber had to be vacuum cleaned only twice owing to the lack of visible accumulation.

2.4.3.2. Malfunctions.

2.4.3.2.1. Barrier Filter. The plastic fasteners which were used to secure the filter element to the structure lacked adequate strength and four of these broke during the test period and were replaced. During a post-test inspection, a piece of broken fastener was found lodged near the bellmouth of the engine.

Two filter elements were used alternately for the first eight flights in sand and dust. Each of the elements sustained damage during the third washing because the tape which bound the edges of the elements became loosened and the wire screen exterior of one was distorted and broken. The elements were repaired by the manufacturer's representative and were re-used. With each washing, the capacity of the filter element to retain trapped dust and sand was decreased (figure 1, appendix I, section 3), and the frequency of required washings was thereby increased. The material in the elements became matted and separated by exposure to the water.

The sponge rubber seal between the filter element and the framework became worn, and dislodged and was replaced after the sixth filter element change.

2.4.3.2.2. Particle Separator. The Particle Separator experienced no malfunctions during the test.

2.4.3.3. Special Tools and Equipment. The Particle Separator required no special tools. A tank, detergent, and running water were required for washing the Barrier Filter element.

2.4.3.4. Desirable Features.

2.4.3.4.1. Barrier Filter. The Barrier Filter possessed no moving parts.

2.4.3.4.2. Particle Separator. The Particle Separator required no maintenance other than visual inspection after flight in sand, dust, and water environments, was readily accessible for visual inspection, and was unaffected by flight in moisture.

2.4.3.5. Undesirable Features.

2.4.3.5.1. Barrier Filter. The Barrier Filter had the following undesirable features:

a. Required excessive servicing and maintenance.

b. Incorporated fasteners which were difficult to operate, lacked adequate strength and were a hazard to the engine in the form of potential foreign object damage.

c. Incorporated a filter element which lacked capacity and durability and which deteriorated in efficiency after each washing.

d. Required special equipment for servicing and maintenance (paragraph 2.4.3.3.1).

e. Created a requirement for a dry, clean storage area for replacement filter elements and additional area for washing equipment.

f. Required the filter element to be folded and otherwise man-handled during removal for cleaning which caused the possibility of some residue in and on the element to become dislodged and fall into the plenum chamber and engine bellmouth.

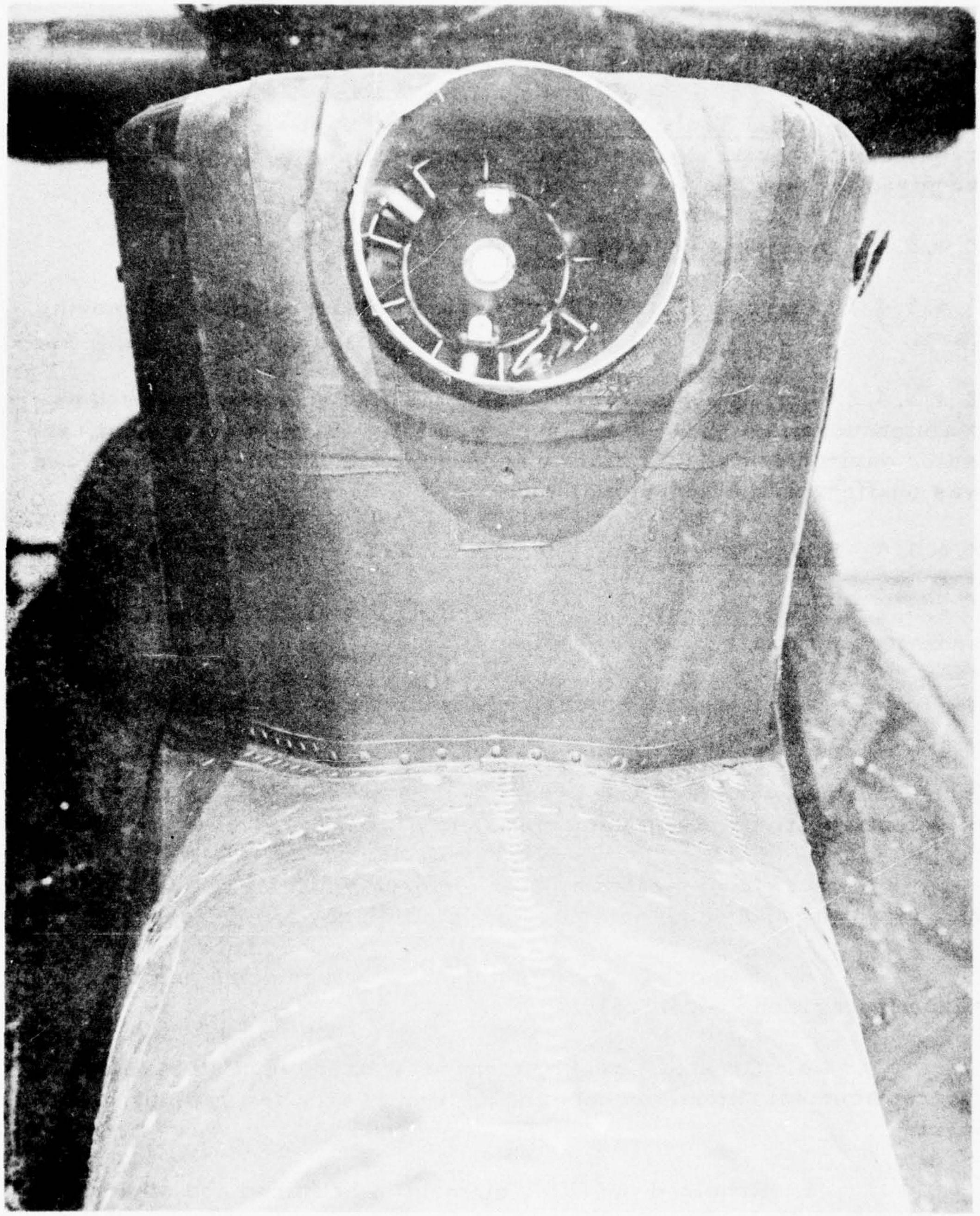


Figure 30. Exhaust fan of Particle Separator seen through scavenge exhaust port.

g. Required a ventilated area protected from dirt and moisture for drying the washed filter elements.

2.4.3.5.2. Particle Separator. The Particle Separator had the following undesirable features:

a. Required brushing by hand of the intake screen following hovering flight in hay area.

b. Incorporated electrically operated exhaust fan.

2.4.4. Analysis.

2.4.4.1. The Particle Separator required less maintenance and servicing and was easier to maintain and service than the Barrier Filter.

2.4.4.2. The Particle Separator experienced no malfunction during the test while the Barrier Filter experienced minor malfunctions in three areas.

2.4.4.3. The Particle Separator required no special tools, and the Barrier Filter required special equipment for servicing.

2.4.4.4. The Particle Separator possessed more desirable and fewer undesirable maintenance features than the Barrier Filter.

2.5. SPECIAL TESTS.

2.5.1. Objective.

To investigate the "migration" of sand particles through the Barrier Filter element during flight.

2.5.2. Technique.

The helicopter, with a clean Barrier Filter element installed, was hovered in the sand environment until the Δp reached 5.6 inches of water. The helicopter was landed, shut down, and the Barrier Filter element was carefully removed, weighed, and reinstalled. The sand trapped in the filter element was disturbed as little as possible during the procedure. The helicopter was then flown for 90 minutes in simulated tactical maneuvers which consisted of cruise, takeoffs,

approaches, and landings to hard surface. The Δp was recorded in flight and at a hover at least once each 15 minutes. At the completion of flight, the filter element was carefully removed and weighed.

2.5.3. Results.

The clean, unused filter element weighed 2.00 pounds before installation. (See flight No. 13, figure 1, appendix I, section 3.) After hovering in the sand, Δp read 5.6 inches of water and the filter element weighed 2.52 pounds. After reinstallation, Δp at a hover was 4.6 inches of water. Following 90 minutes of flight, Δp read 4.8 at a hover and the filter element weighed 2.56, an increase of 0.04 pounds.

2.5.4. Analysis.

Results of the test were inconclusive because of the impossibility of removing, weighing, and reinstalling the filter element without relocating the trapped particles in the element and the corresponding Δp reading at a hover. The increased weight of the element after the 90-minute flight was attributed to an undeterminable amount of foreign material which unavoidably was added to the filter during the hover performance check, the takeoff from the sandy area, and during the remainder of the flight through "clean air." The amount of material, if any, which migrated through the filter during flight was also undeterminable.

SECTION 3 - APPENDICES

APPENDIX I - TEST DATA

Comparative Test of the OH-6A Engine Inlet Filter and Particle Separator

USATECOM Project No. 4-6-0251-05

OH-6A Helicopter, S/N 62-4211

Filter Type: Barrier Filter

Flight Number	1	2	3	4	5	6	7	8	9	11	12	13	Total
Date	3 Nov	4 Nov	4 Nov	5 Nov	9 Nov	10 Nov	10 Nov	10 Nov	11 Nov	18 Nov	18 Nov	22 Nov	
Filter Number	A_1	B_1	A_2	B_2	A_3	B_3	A_4	B_4	A_5	B_5	C_1	D_1	
Hover Time in Dust (min.)	10:00	10:00				10:00	08:00	05:10		04:10			47:20
Idle Time in Dust (min.)	03:00	03:00											06:00
Hover Time in Sand (min.)	01:08	02:25	07:35	05:37	05:55	07:20						25:00	55:00
Idle Time in Sand (min.)				02:00		04:00							06:00
Hover Time in Hay (min.)									38:08				38:08
Hover Time in Water (min.)										10:00	10:00		20:00
Δp, Inches Water Before Hover	3.5	3.7	3.8	4.2	3.8	4.1	3.9	4.1	3.9	4.0	3.4	2.9	
Δp, Inches Water End of Hover	5.7	5.6	5.6	5.7	5.7	5.7	5.8	5.7	5.6	5.6(1)	4.9	5.6	
Δp, Inches Water Before Shutdown	6.0	5.9	6.0	6.2	5.7	5.6	5.8	5.6	5.6	8.0(2)	3.9(3)	4.8(4)	
Filter Weight Before Hover (lb.)	2.12	2.18	2.20	2.32	2.20	2.32	2.30	2.5	---	2.28	2.08	2.00	
Filter Weight After Hover (lb.)	2.79	2.67	2.78	2.88	2.54	2.59	2.50	2.55	---	3.11	---	2.52(5)	
Total Time on Filter (min.)	14:08	15:25	21:43	23:02	27:38	44:22	35:38	49:32	73:46	63:42	10:00	0:25	
Totals for Test (hr:min:sec)	14:08	29:33	37:08	44:45	50:40	1:12:00	1:20:00	1:25:10	2:03:18	2:17:28	2:27:28	2:52:28	2:52:28

(1)End of hover in dust.
(2)End of hover in water with dirty filter.
(3)Includes 7.0 minutes of hover to dry the wet filter (this 7.0 minutes not included in total test time).
(4)Δp at hover after dirty filter was reinstalled was 4.6 after 1:30 hours' flight in clean air, Δ p at hover was 4.8.
(5)The weight of the dirty filter increased from 2.52 to 2.56 during 1:30 hours of flight in "clean" air.

(6) Four filters were used (A, B, C, D). Repeated use is indicated by subnumbers.

Figure 1.

Comparative Test of the OH-6A Engine Inlet Filter and Particle Separator

USATECOM Project No. 4-6-0251-05

OH-6A Helicopter, S/N 62-4216

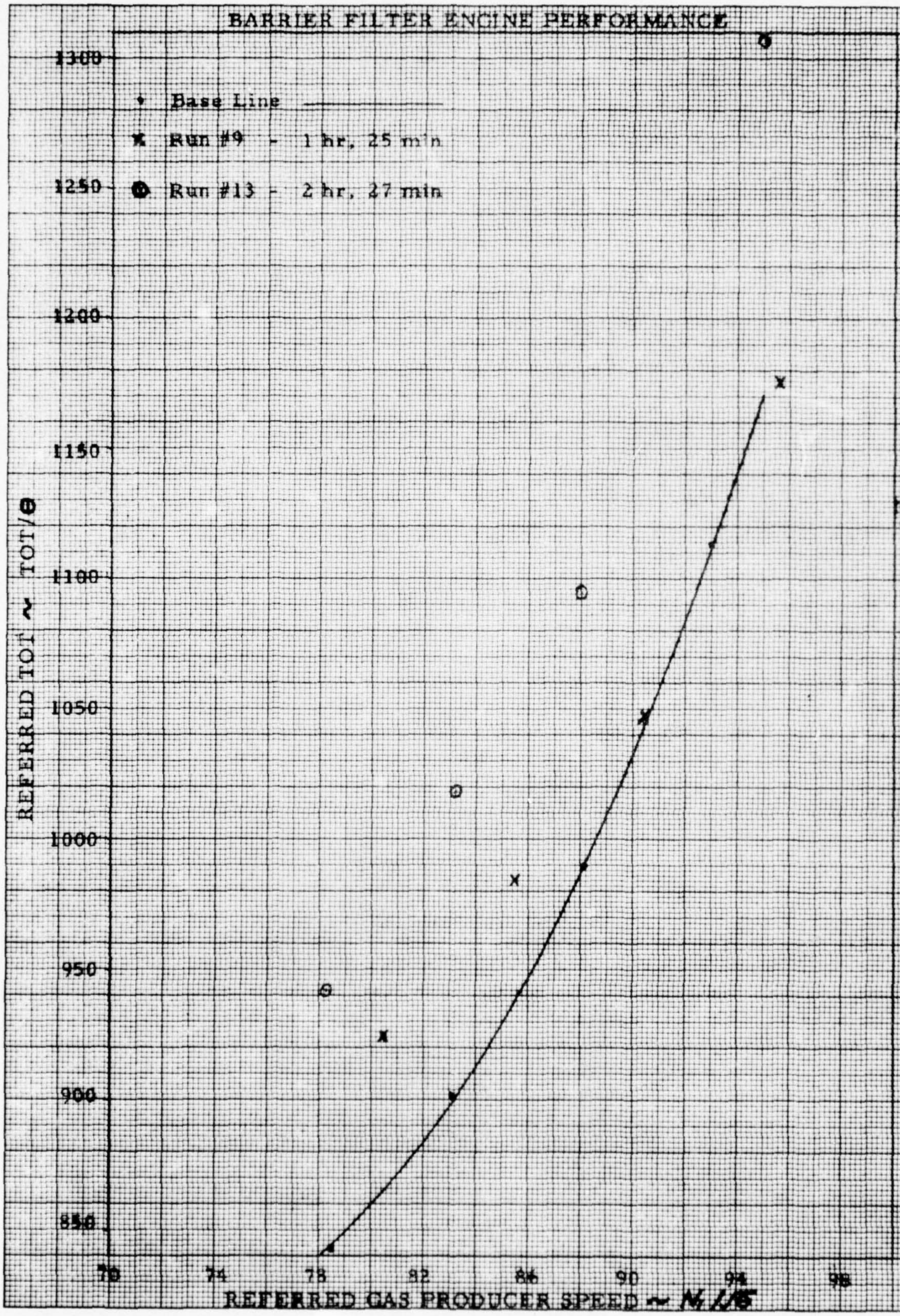
Filter Type: Particle Separator

Flight Number	1	2	3	4	5	6	7	8	9a	9b	9c	9d	9e	10	12	13	Total
Date	3 Nov	4 Nov	4 Nov	5 Nov	9 Nov	10 Nov	10 Nov	10 Nov	11 Nov	11 Nov	11 Nov	11 Nov	11 Nov	11 Nov	18 Nov	22-23 Nov	
Hover Time in Dust (min.)	10:00	10:00				10:00	08:00	05:10						04:10		05:00	5:47:20
Idle Time in Dust (min.)	03:00	03:00															6:00
Hover Time in Sand (min.)	01:08	02:25	07:35	05:37	05:55	07:20										05:00	5:30
Idle Time in Sand (min.)				02:00		04:00											6:00
Hover Time in Hay (min.)									04:05(1)	13:30(1)	10:30(1)	02:00(2)	06:00(2)				36:05
Hover Time in Water (min.)														10:00	10:00		20:00
$\Delta\rho$, Inches Water Before Hover	4.0	3.9	3.8	3.9	3.9	4.2	3.9	3.9	4.1	4.1	3.9	5.2	5.0	3.8	3.9	3.9	
$\Delta\rho$, Inches Water End of Hover	3.9	4.0	4.1	3.9	4.3	4.1	3.9	3.9	5.9	5.6	6.1	5.7	6.0	3.8(3)	3.9	4.1	
$\Delta\rho$, Inches Water Before Shutdown	3.9	4.0	3.8	3.9	4.3	4.1	3.9	3.9	---	---	---	---	4.6	4.1	3.9	4.1	
Total Test Time (hr:min:sec)	14:08	29:33	37:08	44:45	50:40	01:12:00	1:20:00	1:25:00					2:01:15	2:15:25	2:25:25(4)		12:25:25

(1) Hay cleaned from intake screen by hand.
(2) Helicopter flown at cruise in clean air.
(3) At end of hover in dust, $\Delta\rho = 3.8$.
(4) Removed engine S/N 91; installed S/N 92.

Figure 2.

Figure 3.



BARRIER FILTER ENGINE PERFORMANCE
Base Line
Run #9 - 1 hr, 25 min
Run #13 - 2 hr, 27 min
1300
1250
1200
1150
1100
1050
1000
950
900
850
REFERRED TOT ~ TOT/θ
70
74
78
82
86
90
94
98
REFERRED GAS PRODUCER SPEED ~ N/√θ

Figure 4.

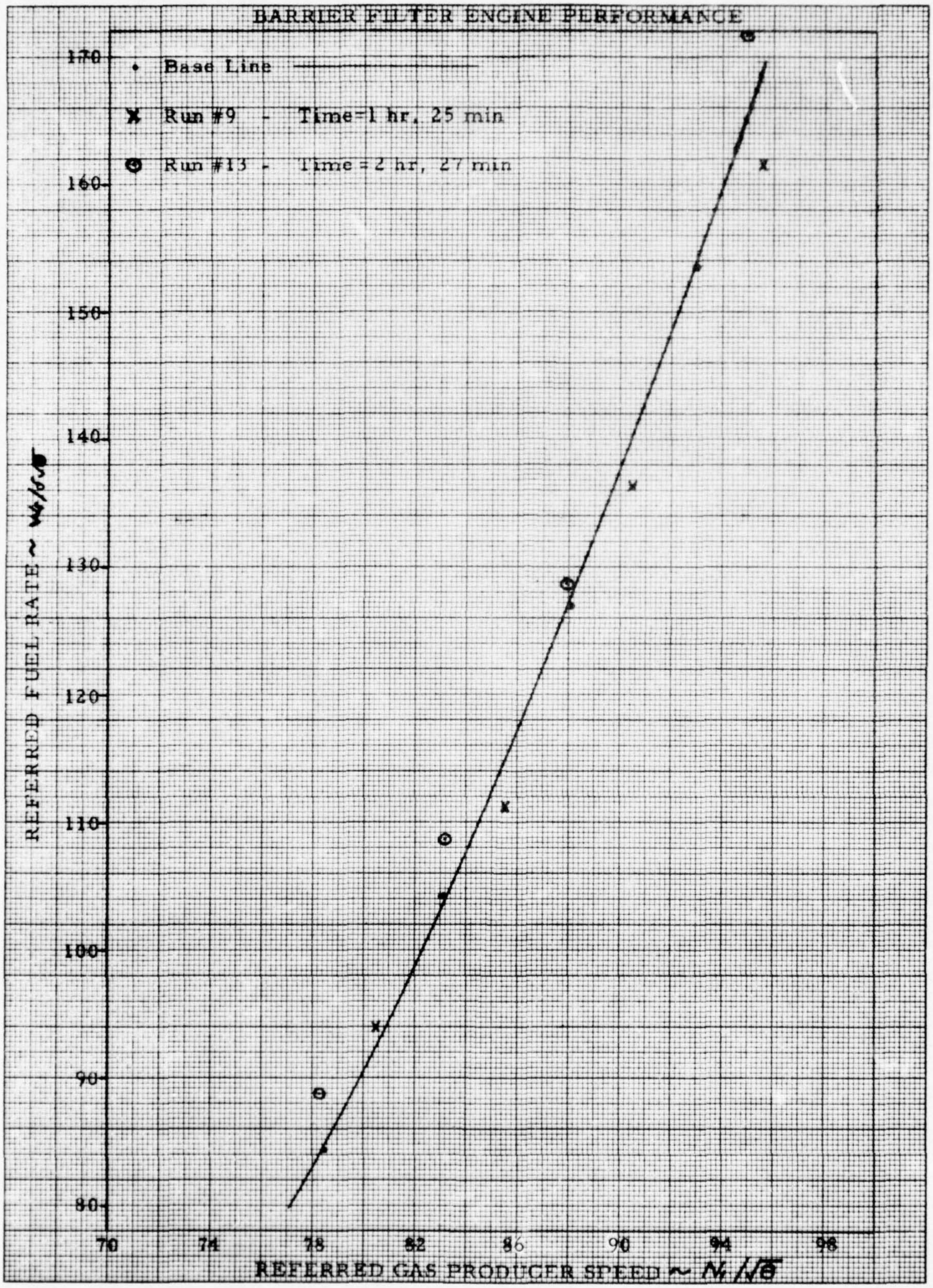

BARRIER FILTER ENGINE PERFORMANCE
Base Line
Run #9 - Time=1 hr, 25 min
Run #13 - Time=2 hr, 27 min
REFERRED FUEL RATE ~
REFERRED GAS PRODUCER SPEED ~
170
160
150
140
130
120
110
100
90
80
70
74
78
82
86
90
94
98

Figure 5.

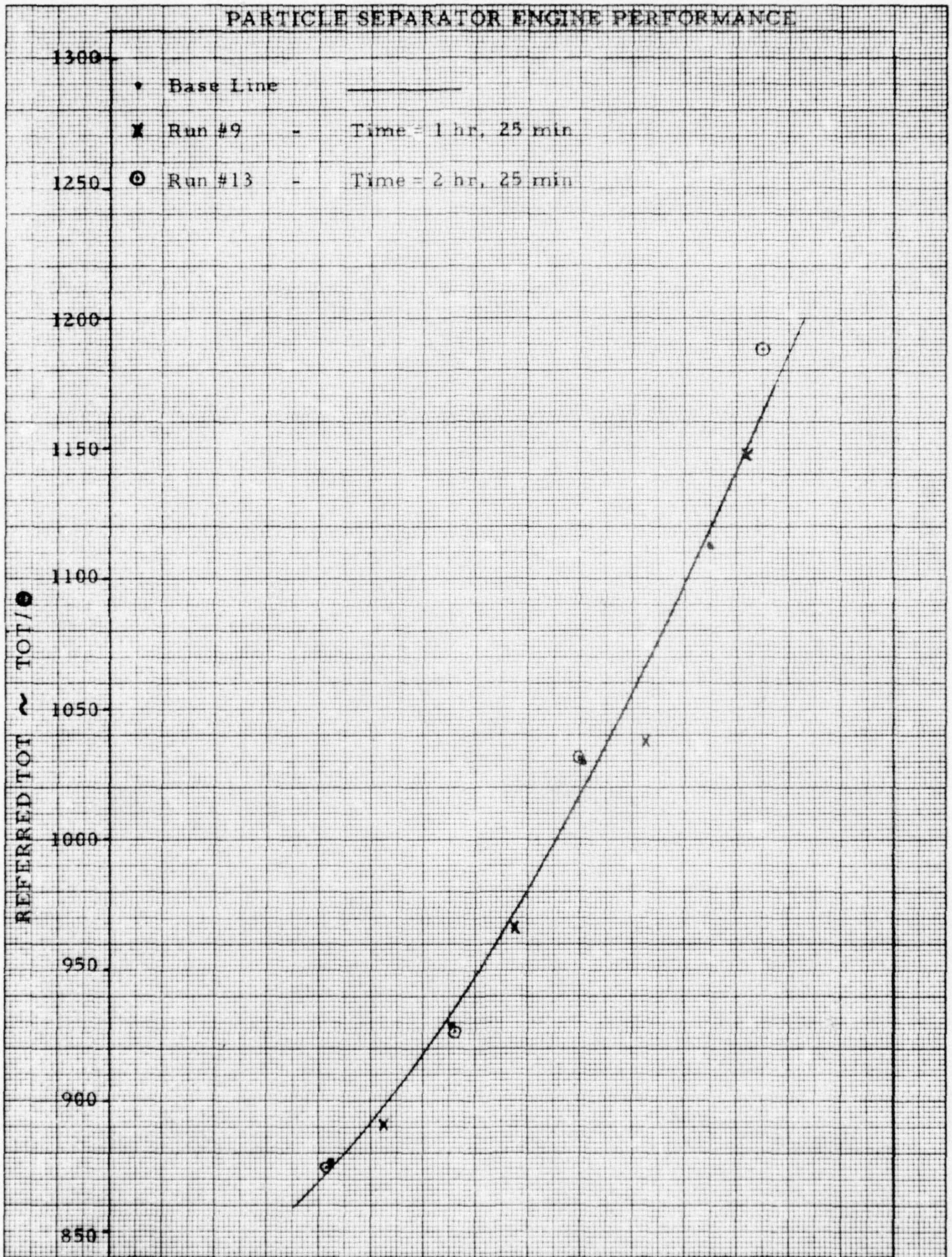

PARTICLE SEPARATOR ENGINE PERFORMANCE
Base Line
Run #9 - Time = 1 hr, 25 min
Run #13 - Time = 2 hr, 25 min
1300
1250
1200
1150
1100
1050
1000
950
900
850
REFERRED TOT ~ TOT/θ
70
74
78
82
86
90
94
98
REFERRED GAS PRODUCER SPEED ~ N₁/√θ

Figure 6.

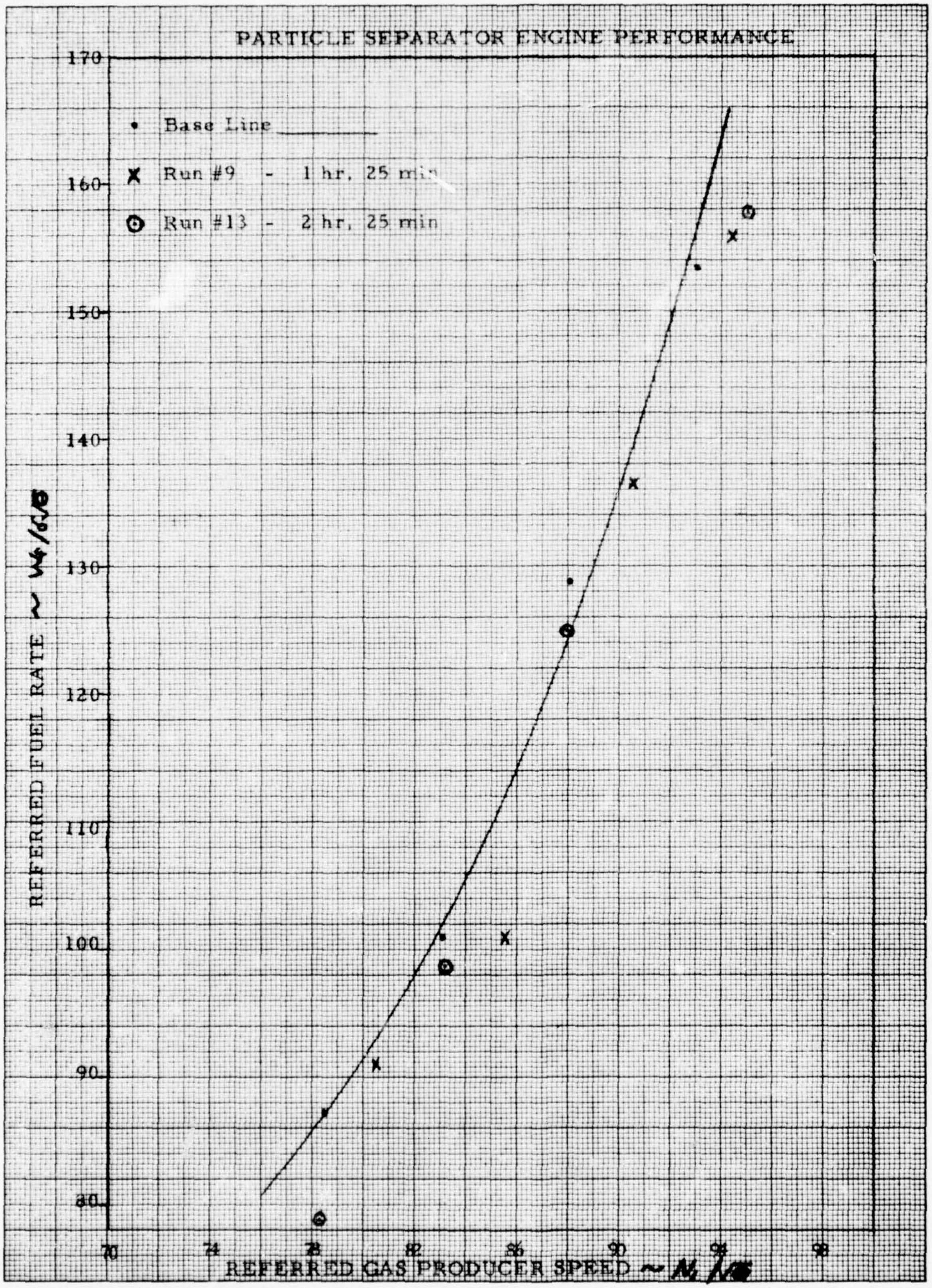

PARTICLE SEPARATOR ENGINE PERFORMANCE
Base Line
Run #9 - 1 hr, 25 min
Run #13 - 2 hr, 25 min
170
160
150
140
130
120
110
100
90
80
70
74
78
82
86
90
94
98
REFERRED FUEL RATE
REFERRED GAS PRODUCER SPEED

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Figure 7.

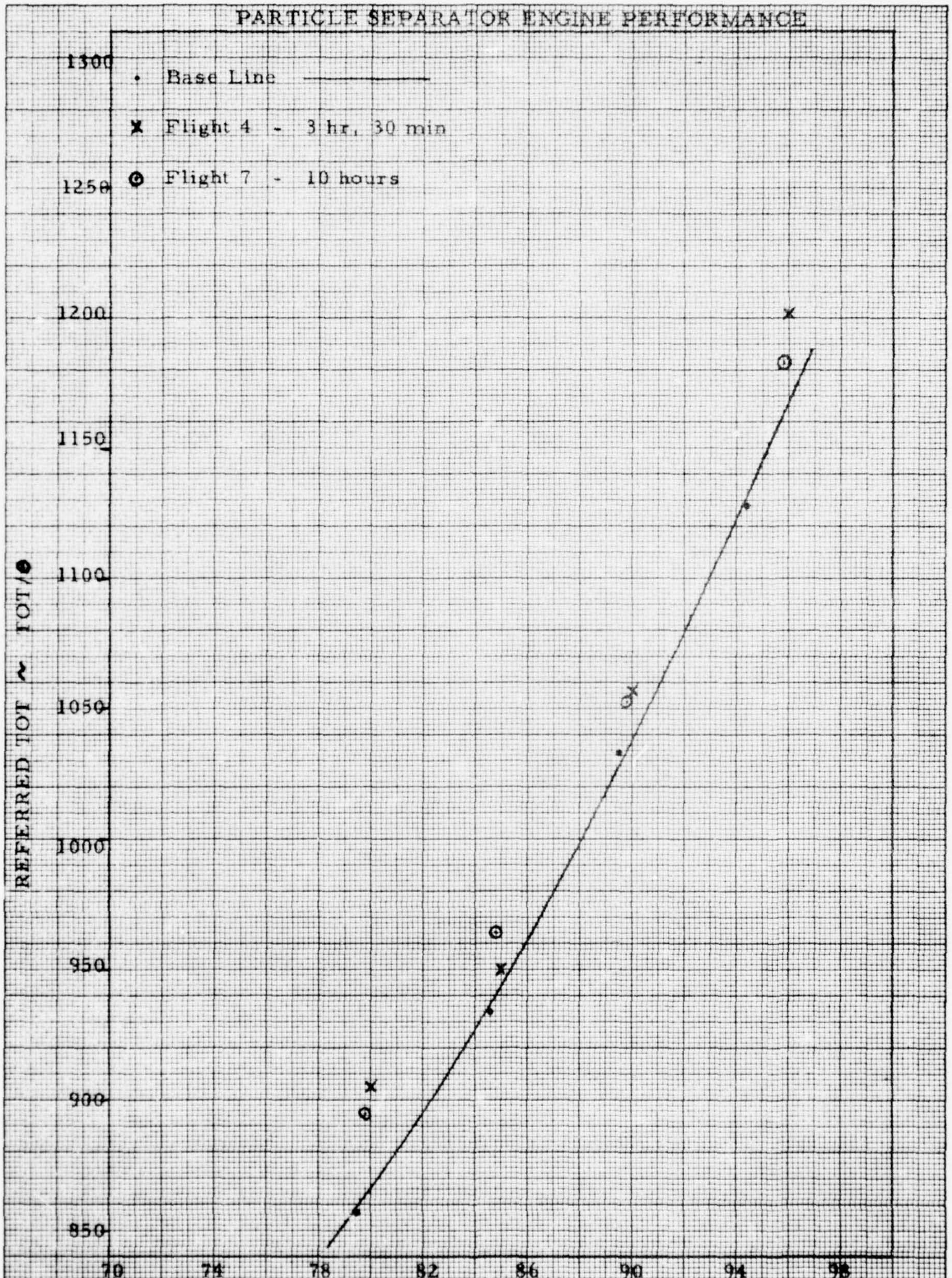

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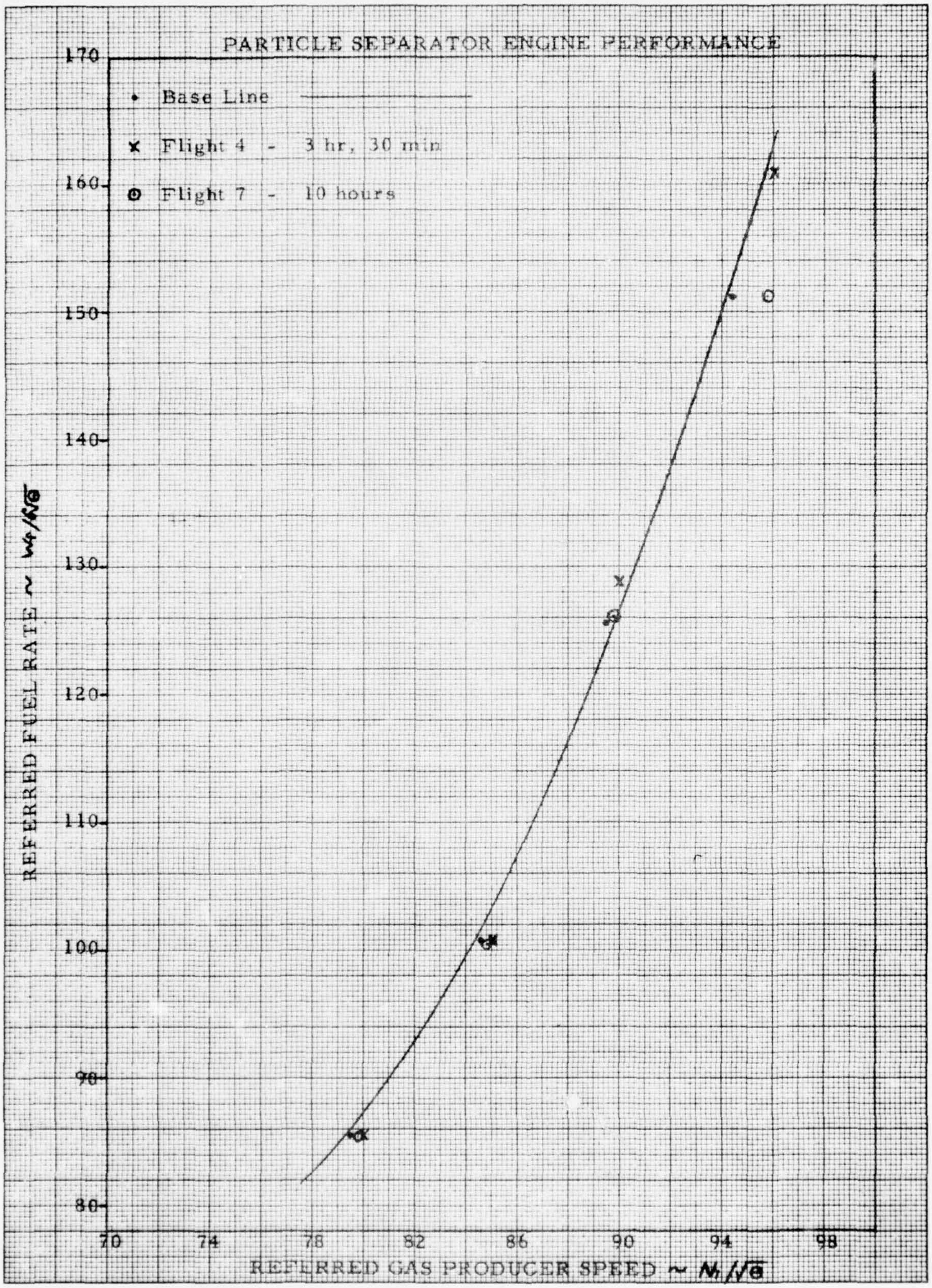
Figure 8.


PARTICLE SEPARATOR ENGINE PERFORMANCE
Base Line
Flight 4 - 3 hr, 30 min
Flight 7 - 10 hours
170
160
150
140
130
120
110
100
90
80
70
74
78
82
86
90
94
98
REFERRED FUEL RATE ~ $W_f/\delta\sqrt{\theta}$
REFERRED GAS PRODUCER SPEED ~ $N_1/\sqrt{\theta}$

COMPOSITION AND MICRON SIZE ANALYSIS

A. Plenum Chamber Sample Weights. During the test, samples of contaminant were vacuumed from the plenum chamber (compartment between the filter device and the engine compressor inlet) of each test helicopter. All accumulation obtained was collected in separate bags, marked for identification and retained for subsequent analysis. Figures 9 and 10 correlate the samples collected to the aircraft number, flight number, sample weight, etc.

B. Micron Size and Distribution. Particle size analysis curves, depicting the micron size and distribution of the samples collected during the test, appear in figures 11 through 15.

C. Discussion.

1. The amount of contaminant found in the plenum chambers gives an indication of the relative efficiency of the filtering devices, as this accumulation has succeeded in passing through the respective filtering system. The samples taken from the plenum chamber of helicopter S/N 62-4211 (Barrier Filter protected) varied in weight from a minimum of 1.09 grams to a maximum of 18.23 grams. Only two samples were vacuumed from the plenum chamber of helicopter S/N 62-4216 (Particle Separator protected), as there was very little evidence of accumulation present. These two samples weighed 0.0605 grams and 0.0136 grams respectively. It is significant to note that

only a small percentage of that contaminant, getting past the respective filtering system, would accumulate in the plenum chamber and not be ingested into the engine compressor inlet.

2. The particle size distribution curves depicted in figures 11 through 15 show the mass median particle size (50% point) passing the Barrier Filter into the plenum chamber to be approximately 85 microns from the dust area and approximately 110 microns from the sand area. The maximum particle size passing was 350 microns from both areas. The two samples taken from the plenum chamber of helicopter S/N 62-4216 (Particle Separator protected) were too small to analyze.

Figure 9.
Plenum Chamber Samples

A/C No.	Flight No.	Sample No.	Weight (gms)	Flight Time (min/sec)
*4211	1	3	6.13	11:08
4211	2	5	2.42	12:25
**4216	2	7	0.06	23:33
4211	3	8	5.30	7:35
4211	4	10	4.81	5:37
4211	5	13	3.78	5:55
4211	6	15	18.23	17:20
4211	7	17	2.42	8:00
4216	8	18	0.01	44:27
4211	8	20	1.09	5:10

*Helicopter S/N 62-4211 employed the Barrier Filter.
**Helicopter S/N 62-4216 employed the Particle Separator.

Figure 10.
Dust Sample Correlation Sheet

Sample No.	Flight No.	A/C No.	Type of Sample
1			Dust sample
2			Sand sample
3	1	4211(1)	From plenum after 11:08 min. flight
4	1	4211	From filter after 11:08 min. flight
5	2	4211	From plenum after 12:25 min. flight
6	2	4211	From filter residue after 12:25 min. flight
7	2	4216(2)	From plenum after 12:25 min. flight
8	3	4211	From plenum chamber after 7:30 min. in sand, filter being cleaned once.
9	3	4211	Residue from filter element No. 3 after being cleaned once and a 7:30 min. flt.
10	4	4211	From plenum chamber after 5:37 min. flt.
11	4	4211	From filter element No. 6 after being cleaned once and a 5:37 min. flt.
12	5	4211	Residue from filter No. 3 after 5:55 min. flt.
13	5	4211	Residue from plenum chamber after 5:55 min. flt.
14	6	4211	Residue from filter No. 6 after 10 min. dust and 7:30 min. sand.
15	6	4211	Residue from plenum chamber after 10 min. dust and 7:30 min. sand.
16	7	4211	From filter after 8:00 min. hover in dust.
17	7	4211	From plenum, 8:00 min. hover in dust.
18	8	4216	From plenum chamber.
19	8	4211	Filter No. 6, 4th exposure 5:10 min. hover in dust.
20	8	4211	From plenum, 5:10 hover in dust.

(1) Engine S/N 400190 with Barrier Filter.
(2) Engine S/N 400191 with Particle Separator.

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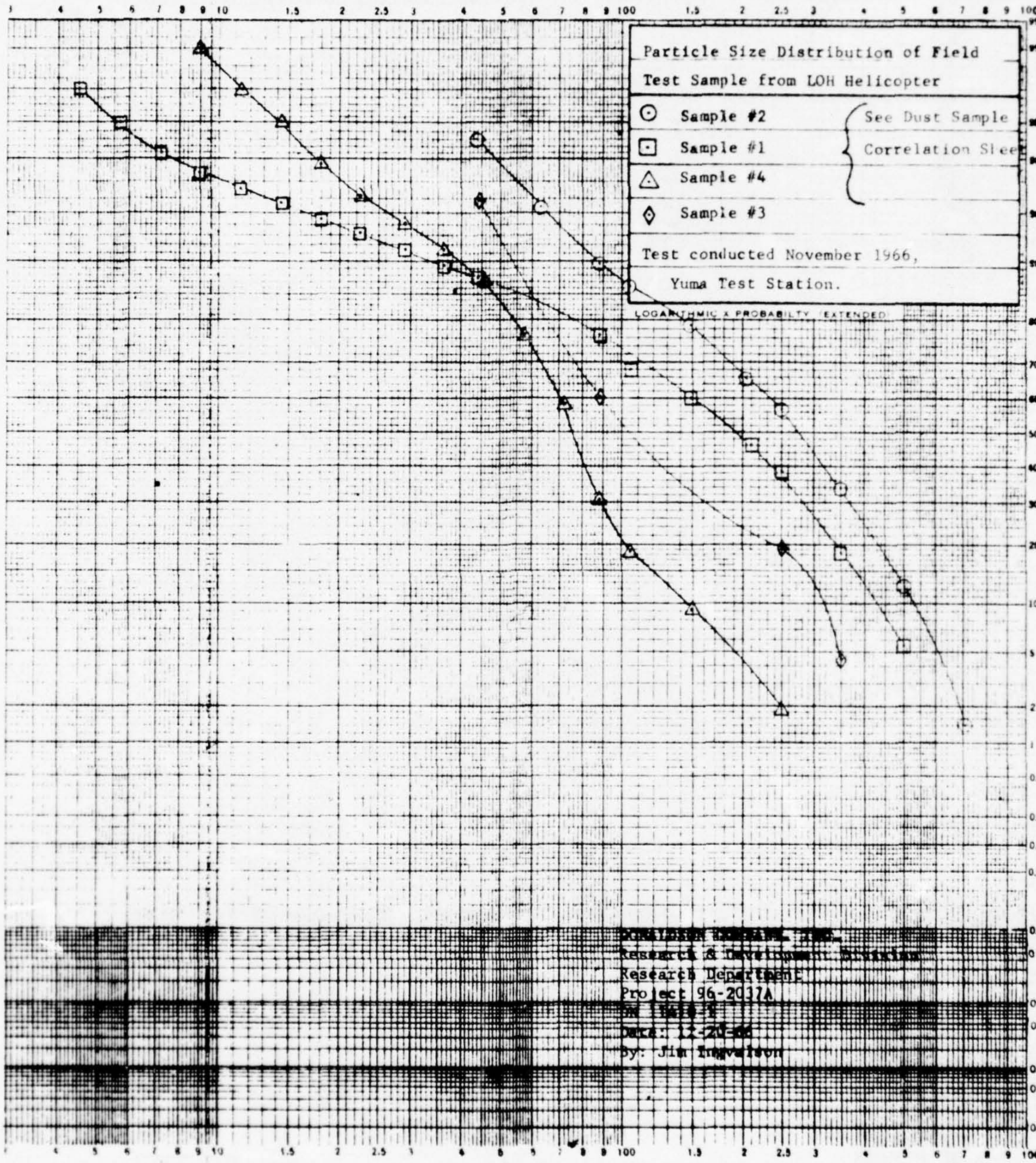
Figure 11.



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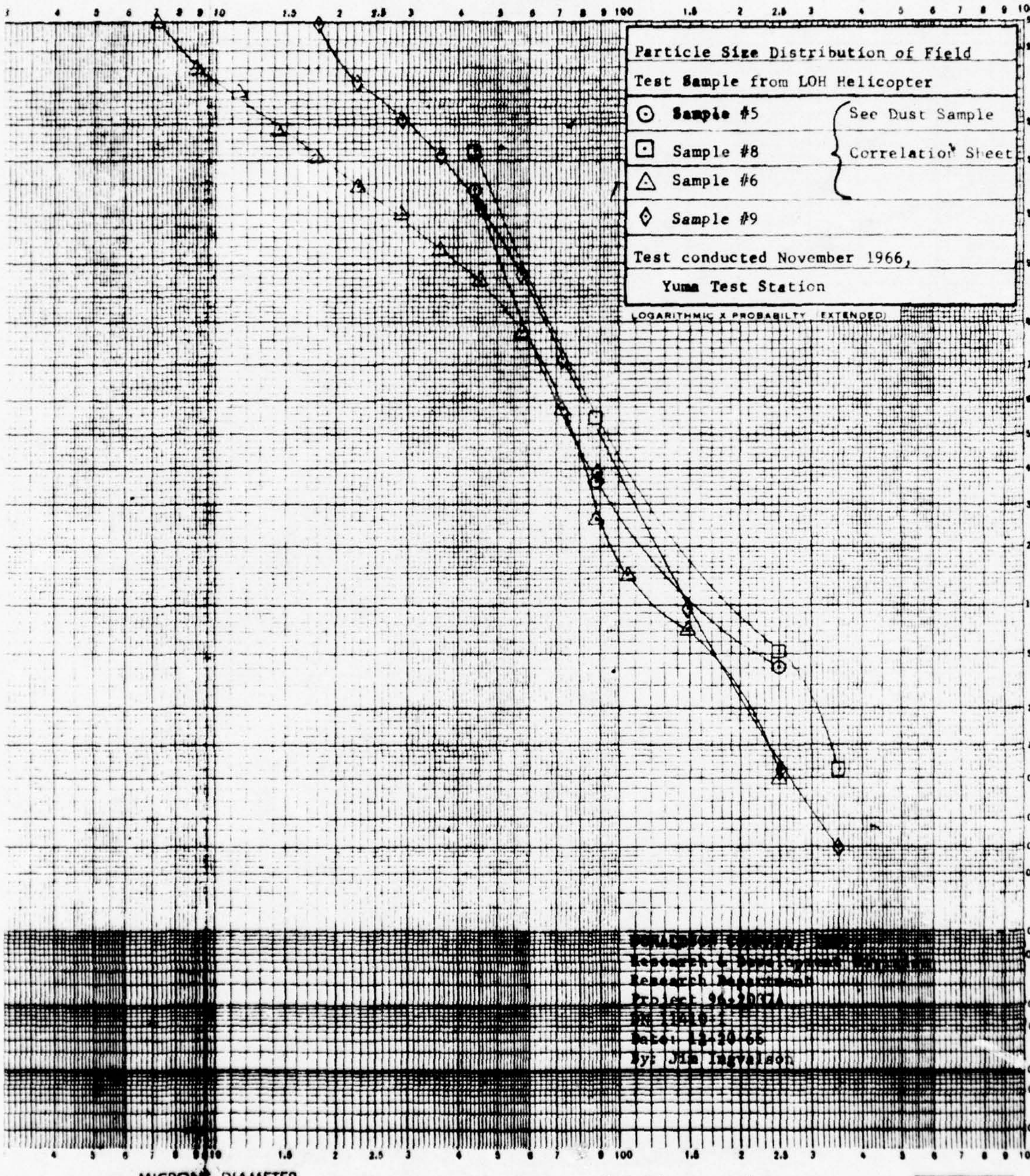
9121E73

Figure 12



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9121E-74

Figure 13.

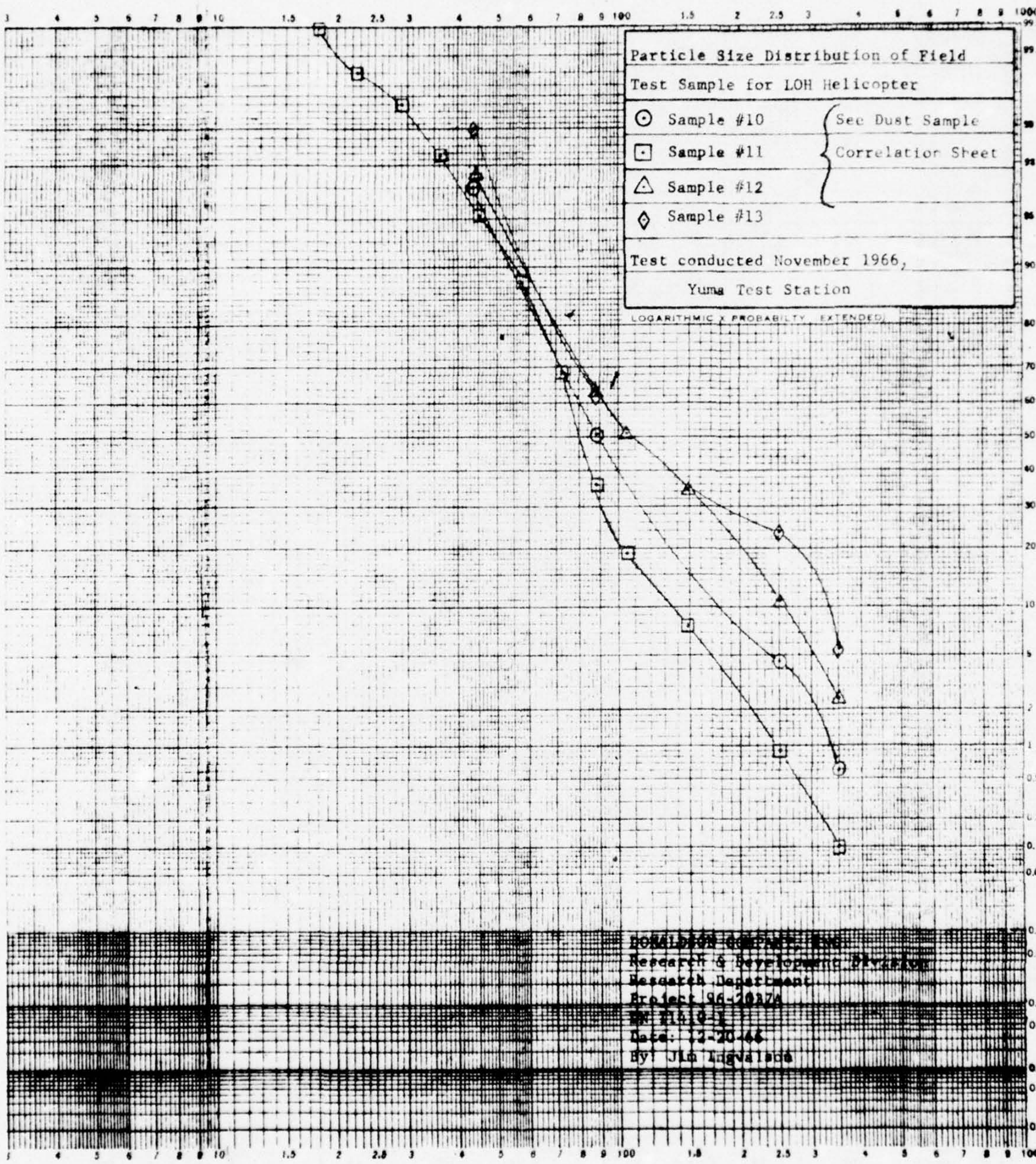
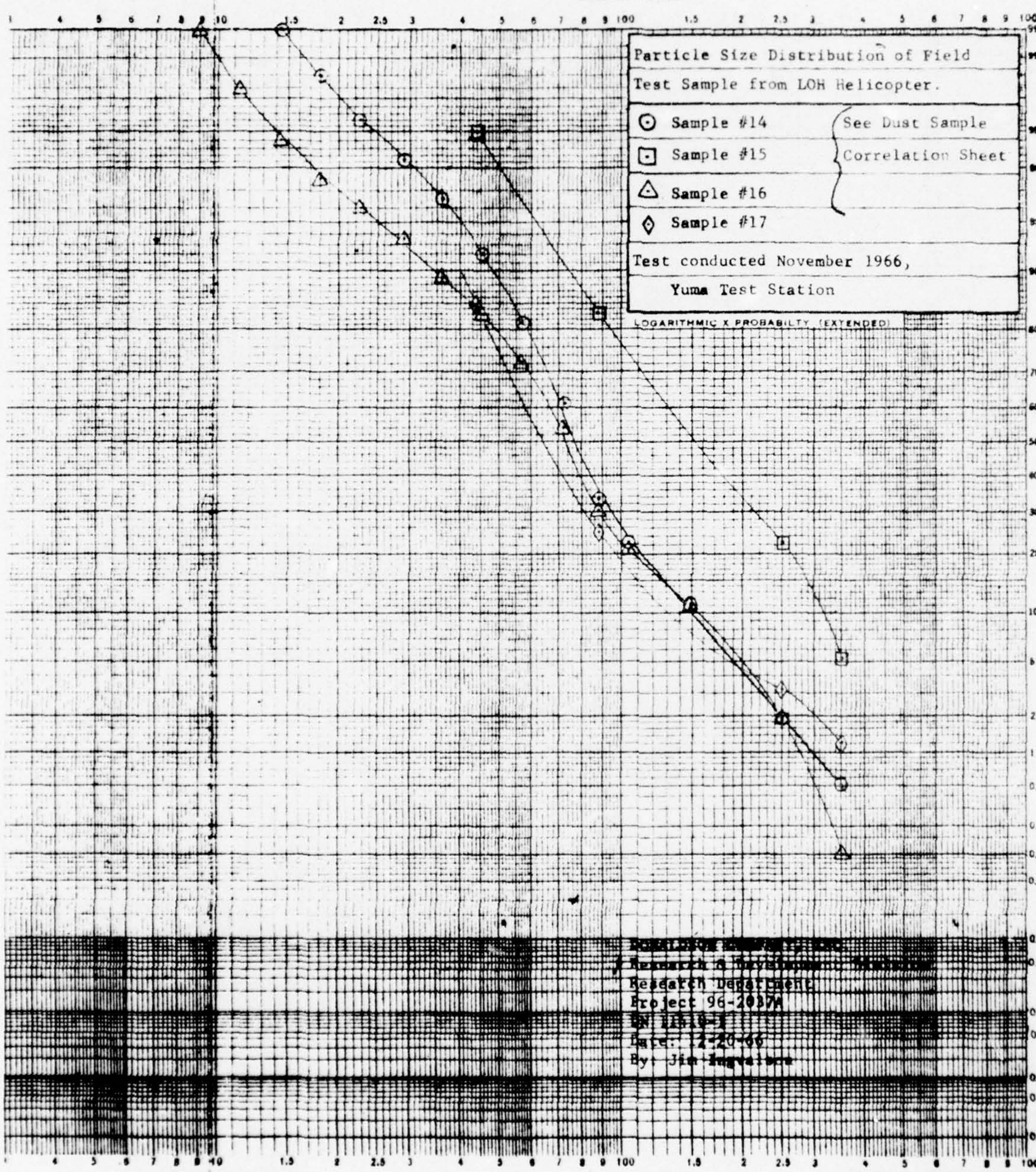

Particle Size Distribution of Field
Test Sample for LOH Helicopter
Sample #10
Sample #11
Sample #12
Sample #13
See Dust Sample
Correlation Sheet
Test conducted November 1966,
Yuma Test Station
LOGARITHMIC X PROBABILITY EXTENDED
Research & Development Division
Research Department
Date: 12-20-66
MICRONS DIAMETER

Figure 14.



9121E-76

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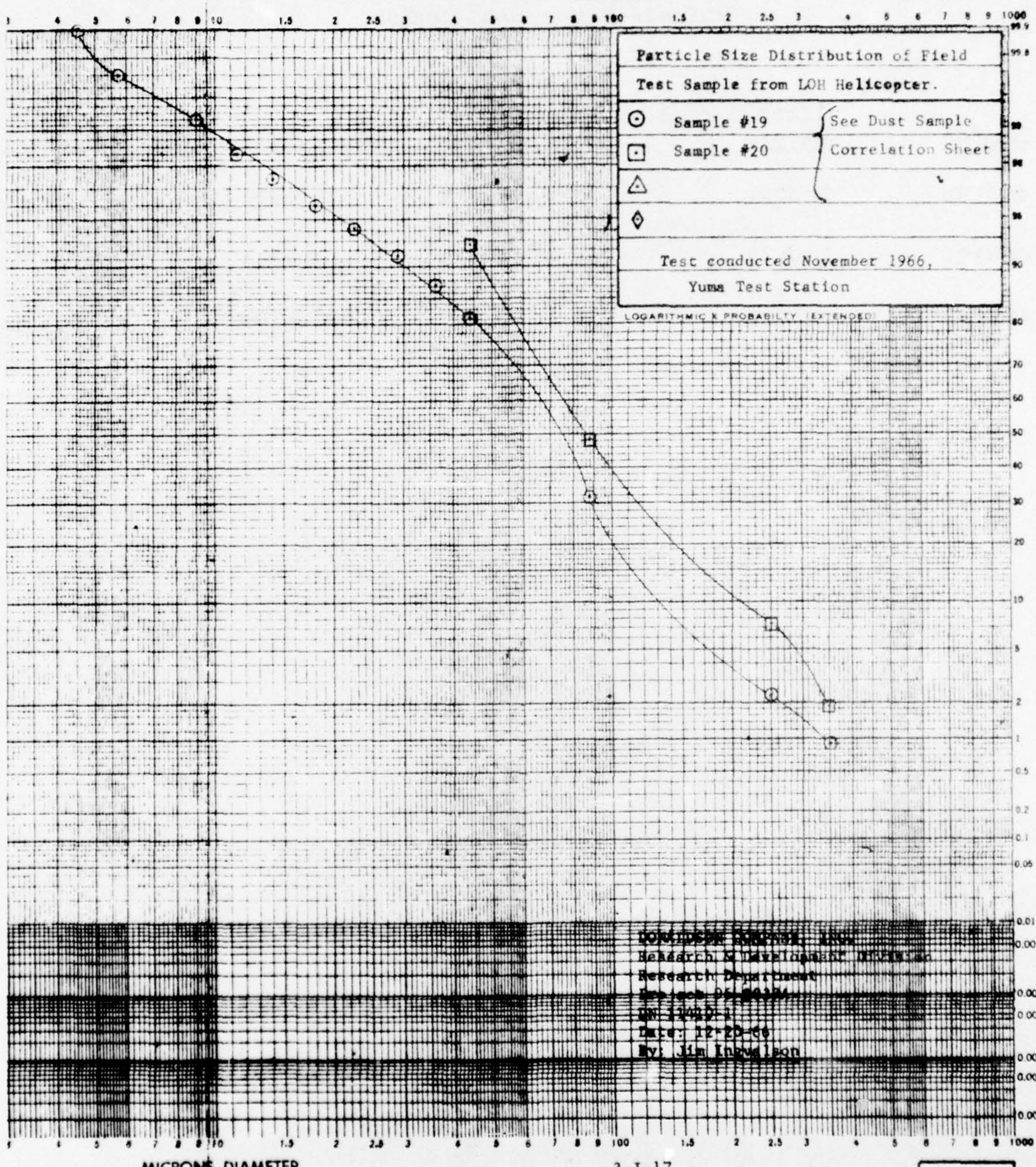
Figure 15.



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9121E-77

Figure 16.

Balance Piston Seal Radius

Engine	Average Seal Radius (In.) Before	After	Radius Increase (In.)
400190	2.0794	2.0874	.0080
400191	2.0824	2.0844	.0020
400192	2.0798	2.0814	.0016

Figure 17.
Blade and Vane Frequencies, Engine S/N 400190

Blades

Stage	New High	New Avg	New Low	Post Test High	Post Test Avg	Post Test Low	Frequency Change CPS	Frequency Change Percent
1	1673	1631	1571	1681	1639	1587	+8	0.5
2	1821	1777	1749	1863	1820	1795	+43	2.4
3	2542	2499	2452	2627	2576	2524	+77	3.1
4	3574	3479	3355	3669	3569	3511	+90	2.6
5	4513	4330	4130	4627	4424	4235	+94	2.2
6	5450	5286	5123	5607	5448	5292	+162	3.1

Vanes

Stage	New High	New Avg	New Low	Post Test High	Post Test Avg	Post Test Low	Frequency Change CPS	Frequency Change Percent
1	932	907	860	914	882	812	-25	2.8
2	947	919	894	903	856	832	-63	7.4
3	1558	1470	1385	1441	1353	1253	-117	8.6
4	1952	1888	1832	1811	1719	1673	-169	9.8
5	2466	2378	2256	2385	2243	2140	-135	3.0
6	2380	2245	2145	2174	2066	1991	-179	3.3

Figure 18.
Blade and Vane Frequencies, Engine S/N 400191

Blades

Stage	New High	New Avg	New Low	Post Test High	Post Test Avg	Post Test Low	Frequency Change CPS	Frequency Change Percent
1	1742	1698	1644	1739	1699	1646	+1	0.0
2	1791	1786	1762	1816	1792	1769	+6	0.3
3	2603	2560	2489	2611	2569	2499	+9	0.4
4	3615	3557	3480	3627	3569	3492	+12	0.3
5	4675	4502	4368	4704	4517	4400	+15	0.3
6	5776	5331	5352	5796	5550	5371	+19	0.4

Vanes

Stage	New High	New Avg	New Low	Post Test High	Post Test Avg	Post Test Low	Frequency Change CPS	Frequency Change Percent
1	865	848	819	855	842	815	-6	0.7
2	1001	934	890	989	919	868	-15	1.6
3	1554	1443	1322	1530	1423	1301	-20	1.4
4	1966	1915	1822	1935	1875	1731	-40	2.1
5	2729	2587	2501	2676	2542	2450	-45	1.7
6	2417	2289	2223	2399	2249	2149	-40	1.7

Figure 19.
Blade and Vane Frequencies, Engine S/N 400192

Blades

Stage	New High	New Avg	New Low	Post Test High	Post Test Avg	Post Test Low	Frequency Change CPS	Frequency Change Percent
1	1741	1671	1625	1741	1672	1622	+1	0.0
2	1828	1801	1777	1843	1813	1796	+12	0.7
3	2660	2574	2530	2687	2618	2554	+44	1.6
4	3545	3410	3249	3580	3445	3273	+35	1.0
5	4517	4413	4334	4545	4441	4363	+28	0.6
6	5699	5535	5199	5765	5586	5245	+51	0.9

Vanes

Stage	New High	New Avg	New Low	Post Test High	Post Test Avg	Post Test Low	Frequency Change CPS	Frequency Change Percent
1	908	871	811	896	856	789	-15	1.7
2	946	907	859	922	870	818	-37	4.1
3	1539	1419	1255	1470	1366	1230	-53	3.7
4	1999	1950	1921	1947	1876	1837	-74	3.8
5	2591	2511	2426	2530	2411	2354	-100	4.2
6	2418	2361	2288	2353	2288	2193	-73	3.1

Figure 20.
Engine Performance Data, Engine S/N 400190

Power Setting	75%	90%	Nor	MIL
Before Dirt Ingestion				
TOT °F.	1148	1226	1280	1380
Shaft Hp.	236	278	300	342
Min. Allow. Spec.	203	243	270	317
% Var. from Spec.	+16.25	+14.40	+11.11	+7.89
Spec. Fuel Cons.	.700	.682	.674	.667
Max. Allow. Spec.	.762	.725	.706	.697
% Var. from Spec.	-8.13	-5.93	-4.53	-4.30
After Dirt Ingestion				
TOT °F.	1148	1226	1280	1380
Shaft Hp.	*197	*237	*266	*315
Min. Allow. Spec.	203	243	270	317
% Var. from Spec.	* -2.96	*-2.47	* -1.50	* -0.63
Spec. Fuel Cons.	*.785	* .740	* .718	* .692
Max. Allow. Spec.	.762	.725	.706	.697
% Var. from Spec.	*+3.02	* +2.07	* +1.70	-0.72

* Asterisked numbers indicate engine performance out of spec. limits.

Percent of Performance Depreciation				
Shaft Hp. Depreciation (%)	-16.53	-14.75	-11.33	- 7.89
Spec. Fuel Cons. Increase (%)	+12.14	+ 8.50	+ 6.50	+ 3.75

Figure 21.
Engine Performance Data, Engine S/N 400191

Power Setting	75%	90%	Nor	MIL
Before Dirt Ingestion				
TOT °F.	1148	1226	1280	1380
Shaft Hp.	237	275	301	346
Min. Allow. Spec.	203	243	270	317
% Var. from Spec.	+16.74	+13.17	+11.48	+9.15
Spec. Fuel Cons.	.705	.679	.672	.658
Max. Allow. Spec.	.762	.725	.706	.697
% Var. from Spec.	-7.48	-6.34	-4.82	-5.60
After Dirt Ingestion				
TOT °F.	1148	1226	1280	1380
Shaft Hp.	231	269	297	340
Min. Allow. Spec.	203	243	270	317
% Var. from Spec.	+13.74	+10.79	+10.00	+7.26
Spec. Fuel Cons.	.722	.693	.680	.667
Max. Allow. Spec.	.762	.725	.706	.697
% Var. from Spec.	-5.25	-4.41	-3.68	-4.30
Percent of Performance Depreciation				
Shaft Hp. Depreciation (%)	-2.53	-2.18	-1.33	-1.73
Spec. Fuel Cons. Increase (%)	+2.41	+2.06	+1.19	+1.37

Figure 22.
Engine Performance Data, Engine S/N 400192

Power Setting	75%	90%	Nor	MIL
Before Dirt Ingestion				
TOT°F.	1148	1226	1280	1380
Shaft Hp.	242	282	310	352
Min. Allow. Spec.	203	243	270	317
% Var. from Spec.	+19.21	+16.05	+14.81	+11.04
Spec. Fuel Cons.	.687	.665	.656	.653
Max. Allow. Spec.	.762	.725	.706	.697
% Var. from Spec.	-9.84	-8.28	-7.08	-6.31
After Dirt Ingestion				
TOT °F.	1148	1226	1280	1380
Shaft Hp.	231	273	299	347
Min. Allow. Spec.	203	243	270	317
% Var. from Spec.	+13.79	+12.34	+10.74	+9.46
Spec. Fuel Cons.	.712	.680	.667	.655
Max. Allow. Spec.	.762	.725	.706	.697
% Var. from Spec.	-6.56	-6.21	-5.51	-6.03
Percent of Performance Depreciation				
Shaft Hp. Depreciation (%)	-4.55	-3.19	-3.55	-1.42
Spec. Fuel Cons. Increase (%)	+3.64	+2.26	+1.67	+0.31

Figure 23.
Turbine Nozzles Flow Area Changes

Nozzle	New Build Area (in. ^{2})	After Dirt Ingestion Area (in. ^{2})	After Dirt Ingestion % Area Change
Engine S/N 400190			
1st-Stage Nozzle (P/N 6845911)	3.44	3.50	+1.75
2nd-Stage Nozzle (P/N 6850944)	5.29	5.24	-0.94
3rd-Stage Nozzle (P/N 6829013)	8.79	9.00	+2.39
4th-Stage Nozzle (P/N 6850943)	11.66	11.77	+0.94
Engine S/N 400191			
1st-Stage Nozzle (P/N 6845911)	3.50	3.62	+3.44
2nd-Stage Nozzle (P/N 6850944)	5.17	5.23	+1.16
3rd-Stage Nozzle (P/N 6829013)	8.75	8.91	+1.82
4th-Stage Nozzle (P/N 6850943)	11.87	11.99	+1.01
Engine S/N 400192			
1st-Stage Nozzle (P/N 6845911)	3.41	3.58	+4.98
2nd-Stage Nozzle (P/N 6850944)	5.11	5.17	+1.17
3rd-Stage Nozzle (P/N 6829013)	8.72	8.91	+2.18
4th-Stage Nozzle (P/N 6850943)	11.75	11.84	+0.77

APPENDIX II

TEST AND CLEANING INSTRUCTIONS FOR THE LOH AIR INLET FILTER

FURNISHED BY THE MANUFACTURER

Aircraft shall be flown with filter installed according to the Army test schedule until the Δp across the filter reaches 4" H_2O. This will be indicated by a light in the cockpit. Pilot shall land as soon as possible after this indication is given. If Δp rises excessively the bypass door will open permitting free flow of inlet air bypassing the filter element.

To remove filter, release the 13 Nylatch fasteners securing the retaining strips around sides and front of filter and remove retaining strips. Filter may now be removed from supporting structure, however if exact weight of dirt picked up by the filter is to be recorded it would be advisable to slip a plastic bag around the element or to insert a plastic sheet under it to collect any dirt which may be lost during removal.

To remove filter from the top fairing the edges must be rolled up around the unit to permit withdrawl through the side access opening.

If the bypass has opened it would be advisable to close or reset it while the element is removed.

Replace a clean filter by again rolling up the edges around the unit and inserting it through the side access opening. The rear edge of the filter should be engaged first ensuring that it is properly inserted into the groove provided by the rear support structure member. Next replace the side and forward retaining strips. Ensure that all the Nylatch fasteners are lined up properly with the mating holes in the structure before pressing them in.

Clean the dirty filter element as following:

1. Rinse filter out from back to front using a low pressure stream of water to remove the majority of entrained dirt.

2. Immerse filter in a container of warm water mixed with a low sudsing detergent. Depth of the solution should be sufficient to completely immerse the filter in an upright position. Water temperature should not be over 120°F. Holding the filter by

one end gently agitate it up and down several times in the solution.

3. Rinse out in a container of clean water or flush off with a low pressure stream of clean water.

4. Shake out excess water and place in sunlight or a warm dry area to dry before reuse. If compressed air is used to remove excess water caution must be observed to prevent damage to the media from a direct blast of high velocity air.

NOTE: If no detergent or tank is available filter may be flushed out using only a low pressure stream of water. This of course will not remove discoloration due to oil or grease.

APPENDIX III - REFERENCES

1. Letter, AMCPM-LHT, Headquarters, US Army Materiel Command, 26 August 1966, subject: "Test of OH-6A Engine Inlet Filter and Particle Separator," with 1st Indorsement, AMSTE-BG, Headquarters, USATECOM, 9 September 1966.

2. Message, AMCPM-LHT, Commanding General, US Army Materiel Command, 29 October 1966, subject: "OH-6A Bar Filter Particle Sep Test."

3. "Sand and Dust Sample Analysis Data," Project 96-2037A, Donaldson Company, Inc., Minneapolis, Minnesota, 28 December 1966.

4. "Post Dust Test Calibration of T63-A-5A Engines Serial Nos. 400190, 400191, 400192," Report No. 67A31, Allison Division, General Motors, Indianapolis, Indiana, 31 January 1967.

5. "Analytical Disassembly and Inspection of T63-A-5A Engine Serial Nos. 400190, 400191, 400192," Report No. PRA-TDR-67-1, Allison Division, General Motors, Indianapolis, Indiana, 7 September 1967.

[redacted]
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11. SUPPLEMENTARY NOTES

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Washington, D.C. 20315

13. ABSTRACT

The USAAVNTBD comparatively tested the Barrier Filter and Particle Separator on the OH-6A at Yuma Proving Ground, Arizona, 29 October - 24 November 1966, accumulating 15.5 hours of operation on two calibrated engines. The engine protected by the Particle Separator suffered less visible erosion, less performance degradation and less moisture impingement than the engine protected by the Barrier Filter. The Particle Separator required less maintenance and servicing, was easier to maintain and service, and had fewer malfunctions (none) than the Barrier which experienced malfunctions in three areas. The test directive specified that the report contain no conclusions and recommendations because of the "possible controversial nature of the test results."

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[redacted]
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Barrier Filter						
Particle Separator						
engine inlet filter						
OH-6A Helicopter						
US Army Aviation Test Board						
T63-A-5A engines						
engine wear						
blade and vane fundamental frequencies						
air-seal radius						
turbine nozzle-flow area						
analytical inspection						
calibrated engines						
FOD migration characteristics						
engine-performance degradation						
maintenance and servicing						

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